

INTERIM REPORT II

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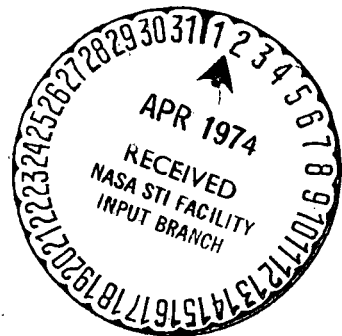
The Influence of Polarization on Millimeter Wave Propagation through Rain

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1. Introduction

This report presents the accumulated data from a 27-month investigation of the influence of polarization on millimeter wave propagation through rain. The authors' intent is to collect all of the pertinent experimental data in one volume for the convenience of NASA and other interested agencies. For a detailed discussion of the millimeter wave depolarization problem, the reader should consult

C. W. Bostian, W. L. Stutzman, P. H. Wiley, and R. E. Marshall, "The Influence of Polarization on Millimeter Wave Propagation Through Rain." Final Report, NASA Grant NGR-47-004-091, VPI&SU, Blacksburg, April 1974.

2. Description of the Experiment

The experimental system used in this project is shown in Figure 1. Basically it consisted of a 1.43 km line-of-sight path with 4-foot (1.22 meter) diameter dual-polarized parabolic reflector antennas at each end. The antennas used were Control Data Corporation (TRG) question-mark mounted scalar feeds. Linearly polarized 17.65 GHz signals were transmitted with their electric field vectors at $+45^\circ$ and -45° from the vertical. These polarizations were initially chosen to maximize the measured depolarization at any given rainfall rate and thus provide as much data as possible. Later it was discovered that the cross polarization levels measured with $+45^\circ$ linearly polarized

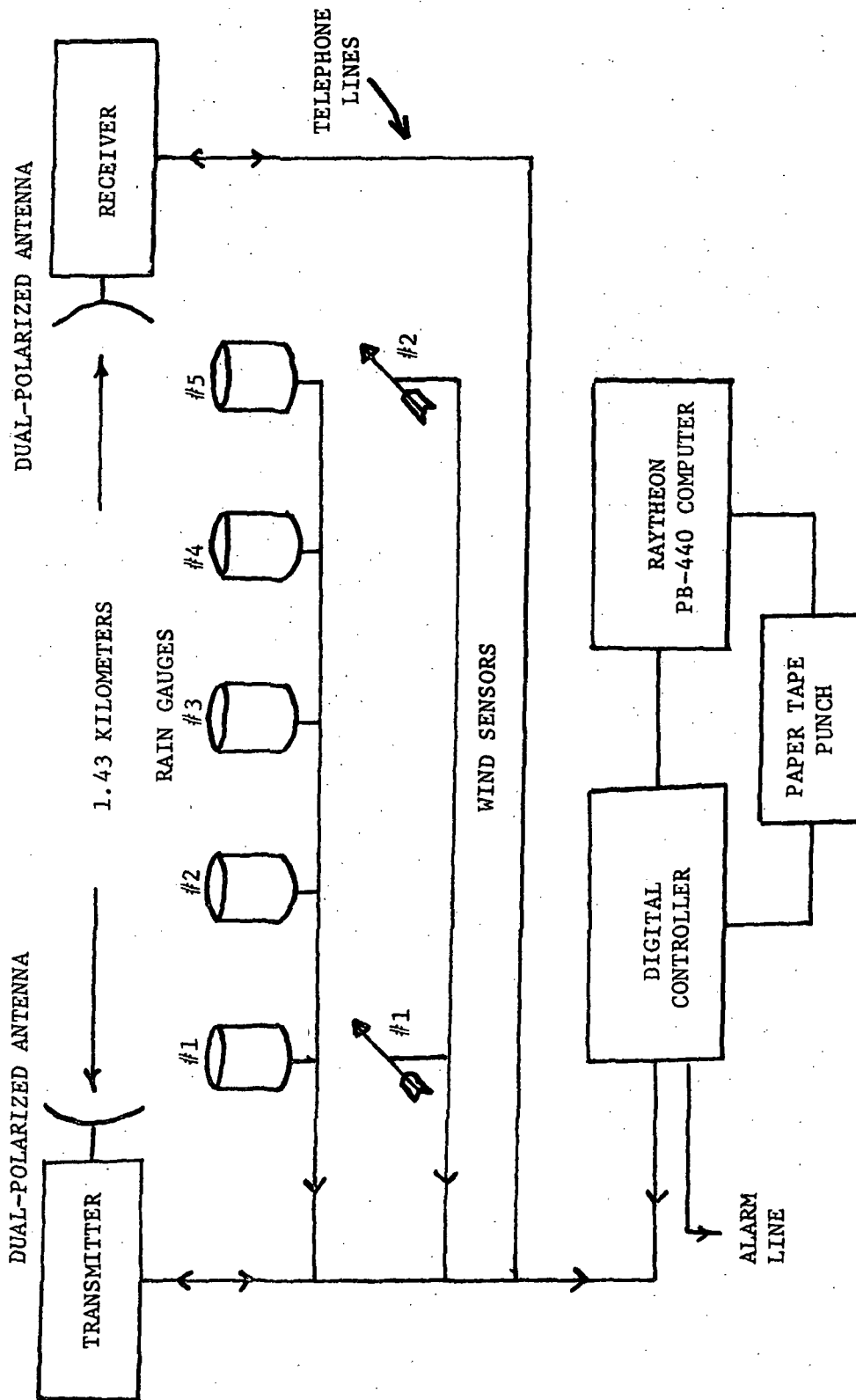


Figure 1. Experiment Block Diagram

signals are theoretically the least sensitive to variations in drop canting angle and this choice of polarization greatly reduces the scatter in the data (in comparison, say, to that which is observed with horizontal and vertical polarization).

The antennas were designed for low residual (i.e. clear weather) cross polarization levels. When the system began operations on August 4, 1972, both channels indicated residual cross-polarization isolations* of -51 dB. As the antennas aged and particularly after the transmitting antenna was invaded by a housefly this high degree of isolation could not be maintained on both channels. After October 6, 1972, the system operated with a nominal - to + isolation of -40 dB and a nominal + to - isolation of -20 dB. This inequality between the channels provided unexpected information on the way in which antenna characteristics influence observed values of rain depolarization.

The propagation path was carefully selected to eliminate depolarization by ground reflection or other multipath phenomena. The common volume formed by the main beams of the two antennas did not intercept the ground or any other obstacle. The angle to the ground at midpath from either antenna was 2° and the angle from the mainbeam maximum to the first null of the radiation pattern was about 1° . Therefore only sidelobes intercepted the ground and any multipath effects were more than 40 dB below the direct signal.

* Inverting P. A. Watson and M. Arbabi's definitions to match the data display conventions used in this report, cross polarization isolation is the decibel ratio of (a) the power coupled into one receiver channel from the orthogonally polarized transmitting antenna channel to (b) power coupled into the same receiver channel from the co-polarized transmitting antenna channel.

Underneath the path were five tipping-bucket rain gauges, spaced about 300 meters apart. These were connected to the data processing system by leased telephone lines. Wind sensors were installed at two rain gauge locations.

A Raytheon PB 440 computer assisted by a special-purpose controller operated the experiment, acquired data, and performed preliminary data processing. The experimental control program maintained the system in the proper operating mode for existing weather conditions and signal behavior. The clear weather operating mode was called mode 0, and in it the $+45^{\circ}$ transmitter channel operated continuously while the computer monitored the $+45^{\circ}$ to -45° cross polarization level and the $+45^{\circ}$ direct attenuation. Both receiver channels were sampled at 10 second intervals while wind velocity and transmitter power were sampled every 100 seconds. If the cross polarization level (in dB) changed by more than 2% or if one of the rain gauges reported precipitation, the system began operating in mode 1. During mode 1 operation, transmission was sequenced at 4 second intervals from the $+45^{\circ}$ to the -45° channel and then to both channels. Receiver sampling occurred at 1 second intervals and wind velocity was sampled every four seconds. Mode 1 operation continued until the precipitation rate fell below 6 mm/hr or until the cross polarization level stabilized. At this time, mode 2 operation began with transmitter switching at 10 second intervals and receiver and wind sampling at 2 and 10 second intervals respectively. Mode 2 operation continued until the precipitation rate fell below 3 mm/hr. The system then entered mode 3 with transmitter switching at 100 second intervals and receiver and wind sampling at 10 and 100 second intervals

respectively. When the precipitation rate fell below 2 mm/hr, the system re-entered mode 0 operation. In all modes there was a low pass filter (time constant = 0.4 seconds) at the input to the A-D converter which suppressed fast scintillations of the signals and insured that average values were sampled.

When a new data point entered the PB 440 computer, a program located the last two values stored for that input. If the new value and the last value differed by more than 1% the new value was stored. If the difference between the new value and the last value was less than 1%, the new value was compared to the next to last value. If these differed by more than 1%, the new value was stored; if this difference was less than 1%, the last value was discarded and the new value took its place.

An IBM 370/155 computer program was developed which processed, analyzed, and plotted the accumulated data from any number of selected storms. These data were rain rates from each gauge plus quasi-instantaneous (i.e. short integration time) samples of the analog signal levels during a storm. The latter were stored at essentially regular times while the intervals between successive rain gauge trips were random. Before data from different inputs could be compared the computer was required to generate a time-function representation for each variable. These time functions were then averaged over selected time intervals to generate the average signal levels, rain rates, etc., required by steady state theory.

A detailed history of the project and description of the experimental system may be found in the following reports.

1. C. W. Bostian and W. L. Stutzman, "The Influence of Polarization on Millimeter Wave Propagation Through Rain," Semi-Annual Status Report I, NASA Grant NGR-47-004-091, VPI&SU, Blacksburg, July 1972 (NASA-CR-130107).
2. C. W. Bostian and W. L. Stutzman, "The Influence of Polarization on Millimeter Wave Propagation Through Rain," Semi-Annual Status Report II, NASA Grant NGR-47-004-091, VPI&SU, Blacksburg, January 1973 (NASA-CR-132074).
3. C. W. Bostian, W. L. Stutzman, P. H. Wiley, and R. E. Marshall, "The Influence of Polarization on Millimeter Wave Propagation Through Rain," Semi-Annual Status Report III, NASA Grant NGR-47-004-091, VPI&SU, Blacksburg, July 1973 (NASA-CR-132819).

3. Guide to the Data

Data are presented in this report for 22 storms. Table 1 (1972) and Table 2 (1973) list the dates and times of these storms, their peak rain rates, and the number of retained data points. In these tables, RG stands for rain gauge, T stands for transmitting, and R stands for receiving. Thus, during August 4, 1972, storm rain gauge 1 recorded 3.81 mm of rain, tripping 15 times in the process, and 68 signal level samples were recorded on the $+45^\circ$ receiver channel with the $+45^\circ$ transmitter channel on and the -45° transmitter channel off.

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Date	Local Starting Time	Local Ending Time	Storm Duration, Seconds	Peak 15-second Averaged Path Rain Rate, mm/hr.	Total Rain Accumulation, mm	Number of Retained Data Points
18. 4	15:42:13.4	16:04:13.0	1319.6	37.3	3.81	15
18. 17	19:46:56.0	20:50:31.2	3815.2	104.2	6.35	25
Sept. 29	22:54:46.2	23:55:36.8	3650.6	45.5	4.57	18
Oct. 27	22:30:11.8	22:41:38.8	687.0	26.0	1.52	6
Nov. 13	22:20:54.8	23:03:43.0	2568.2	16.6	2.03	8
Nov. 14	00:20:13.4	00:55:34.6	2121.2	32.7	8.11	32
					8.88	35
					8.37	33
					9.14	36
					7.61	30
						2
						112
						11
						50
						5
						3

Table 2. Summary of 1973 Storms

Date	Local Starting Time	Local Ending Time	Storm Duration, Seconds	Peak 15-second Averaged Path Rain Rate, mm/hr	Total Rain Accumulation, mm	Number of Retained Data Points
March 16	16:26:34.4	19:57:08.4	12634.0	129.6	22.4 23.4 26.7 24.6 21.8	RG #1 RG #2 RG #3 RG #4 RG #5
March 17	00:38:28.0	06:24:59.4	20791.4	35.7	7.4 15.5 13.2 16.0 14.5	RG #1 RG #2 RG #3 RG #4 RG #5
May 23	21:26:31.6	21:38:46.2	734.6	41.7	3.6 4.6 *	RG #1 RG #2 RG #3 RG #4 RG #5
May 26	15:23:57.8	15:39:38.8	941.0	44.4	2.5 3.3 3.0 2.3 2.3	RG #1 RG #2 RG #3 RG #4 RG #5
May 27	22:32:12.0	23:12:53.6	2441.6	48.3	6.9 7.1 5.8 6.9 5.3	RG #1 RG #2 RG #3 RG #4 RG #5
May 28	01:03:34.0	02:19:16.2	4542.2	138.0	23.4 27.2 26.4 27.7 23.4	RG #1 RG #2 RG #3 RG #4 RG #5

* Telephone company disconnected this gauge during line maintenance.

Table 2. Summary of 1973 Storms (Cont.)

Date	Local Starting Time	Local Ending Time	Storm Duration, Seconds	Peak 15-second Averaged Path Rain Rate, mm/hr	Total Rain Accumulation, mm	Number of Retained Data Points
June 6	16:50:52.4	17:22:44.0	1911.6	49.5	4.1 4.6 4.3 4.8 3.3	16 18 17 19 13 19 23 19 77 13 11
June 15	20:19:25.6	20:45:12.8	1547.2	36.3	5.3 6.1 0.0 8.1 4.8	21 24 0 32 19 12 43 54 80 32 5
June 17	21:29:00.0	22:29:39.6	3639.6	91.2	34.8 33.3 0.0 36.6 27.9	137 131 0 144 110 12 31 17 92 22 13
June 29	19:15:33.4	19:51:26.8	2153.4	42.7	3.0 3.6 0.0 3.8 3.3	12 14 0 15 13 35 45 47 88 25 12
July 14	23:23:33.0	23:55:55/0	1942.0	55.6	13.5 13.5 14.2 14.5 11.9	53 53 56 57 47 39 90 65 124 34 7
July 20	16:48:06.8	16:52:48.2	281.4	38.5	3.3 3.6 1.5 2.5 1.5	13 14 6 10 6 8 11 6 28 22 23
July 22	13:10:34.4	13:18:22.8	468.4	63.8	5.3 5.3 2.5 3.8 3.6	21 21 10 15 14 48 20 28 31 5 5
August 1	14:12:19.4	14:49:56.6	2257.2	68.6	0.0 7.9 15.2 18.0 14.5	0 31 60 7 1 57 59 91 80 71 29 23
August 20	11:06:28.6	11:29:44.6	1396.0	53.1	3.6 4.8 0.0 7.9 9.1	14 19 0 31 36 14 18 30 45 23 10
October 2	16:19:32.2	16:26:02.2	390.0	54.1	2.0 0.0 0.0 3.3 2.8	8 0 0 13 11 15 8 14 26 11 6

For most of the storms there are 11 plots. These are:

1. Path-average rainfall rate versus time. Each point represents the running 15-second time average of the path-average rainfall rate at the instant plotted.
2. Cross polarization isolation versus time. Each point represents the 15-second running average cross polarization isolation for one channel. In these plots, a Δ represents the isolation I_{-+} where

$$I_{-+} = 20 \log_{10} \left| \frac{E_{- \text{ to } +}}{E_{++}} \right| \quad (1)$$

and $E_{- \text{ to } +}$ = + channel received signal when the - channel (only) is transmitting

E_{++} = + channel received signal when the + channel (only) is transmitting.

A \square represents the isolation I_{+-} where

$$I_{+-} = 20 \log_{10} \left| \frac{E_{+ \text{ to } -}}{E_{--}} \right| \quad (2)$$

and $E_{+ \text{ to } -}$ = - channel received signal when the + channel (only) is transmitting

E_{--} = - channel received signal when the - channel (only) is transmitting.

3. Attenuation versus time. Each point represents the 15-second running average for one channel. A Δ represents the + channel and a \square represents the - channel. The reader should keep in mind that when rain attenuation is measured the instantaneous signal is subtracted from a reference signal. The reference signal should be the nominal clear weather value, and this showed some small drift between storms. For this reason, attenuation measurements may be expected to be slightly less repeatable than cross polarization measurements.
4. Cross polarization isolation versus rain rate scatter plot.
In this plot the 15-second running average cross polarization isolation is displayed versus the 15-second path average rain rate at 1-second intervals. A + represents I_{-+} and a \square represents I_{+-} .
5. Average cross polarization isolation versus rain rate for each channel. For each channel all of the points from 4 above for a given 1 mm/hour increment of rain rate have been averaged. The vertical bars extend from one standard deviation above the average to one standard deviation below the average. A + represents I_{-+} and a \square represents I_{+-} . The points shown by a Δ are the theoretical values of cross polarization isolation ignoring the antenna effects for 40% oblate drops. For the way in which the antennas modify the theoretical curve see the Final Report for this grant. The theoretical curve was calculated using 19.3 GHz scattering coefficients.

6. Average cross polarization isolation versus rain rate. In this graph all of the points from 4 above falling in each integer increment of rain rate have been averaged together without regard to their channel of origin. Vertical bars indicate plus and minus one standard deviation.
7. Attenuation versus rain rate scatter plot. This corresponds to 4 above with a + representing + channel attenuation and a | representing - channel attenuation.
8. Average attenuation versus rain rate for each channel. This plot is analogous to 5 above.
9. Average attenuation versus rain rate. This is analogous to 6 above.
10. Attenuation versus cross polarization isolation scatter plot. This plot was generated by plotting each attenuation point in 7 versus the corresponding cross polarization isolation from 4.
11. Average attenuation versus average cross polarization isolation. This graph displays average attenuation (both channels together) versus average isolation for each integer rain rate.

4. Comments on Particular Storms

The storms of July 20, 1973, and October 2, 1973, were too short for our time history generating program. For this reason no time histories of these storms appear in this report.

Due to equipment malfunction data from only one receiver channel were stored during the storms of August 4, 1972, and May 27, 1973. These storms have nine plots rather than the full set of 11.

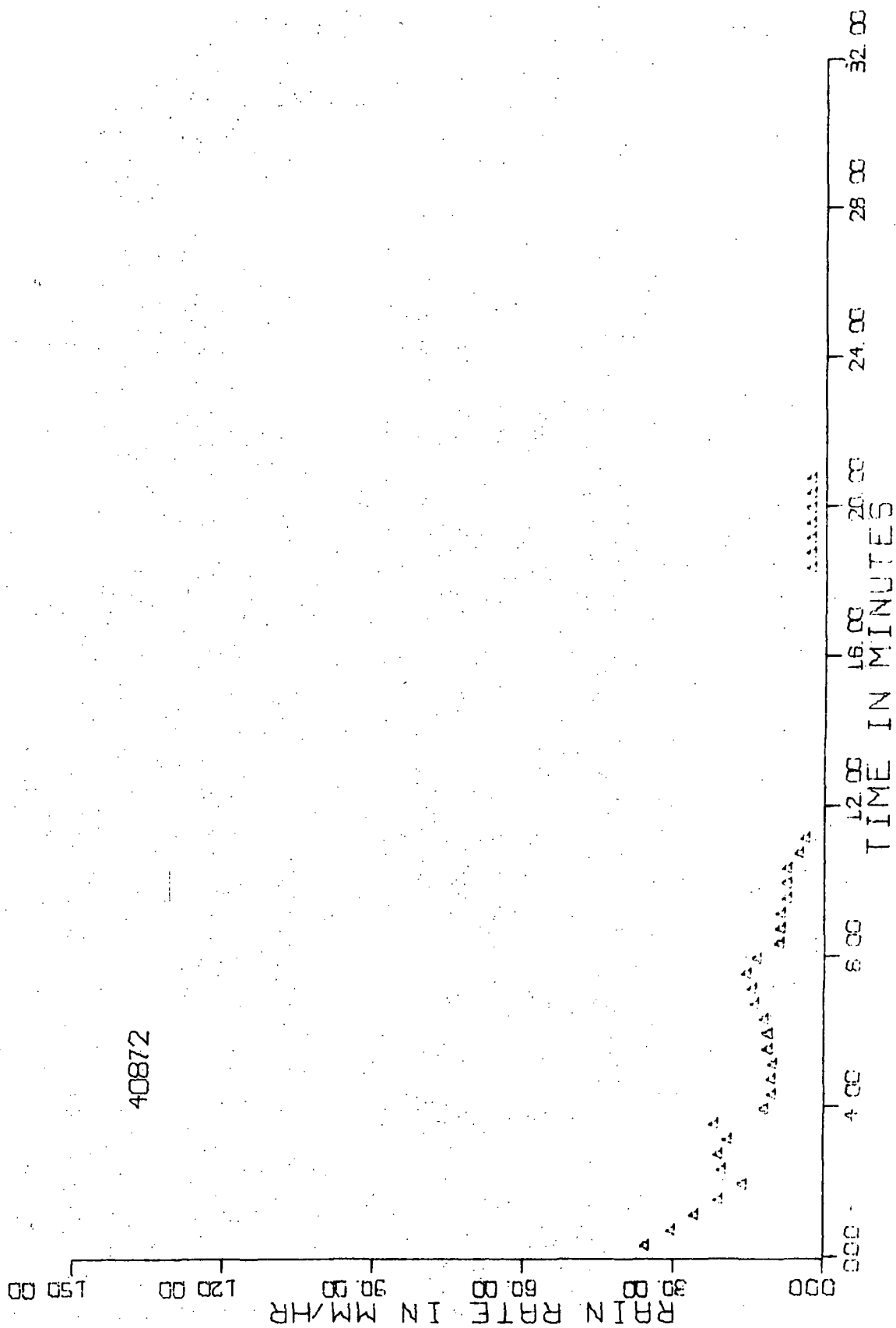
Over the course of the project several changes were made in the experimental system.

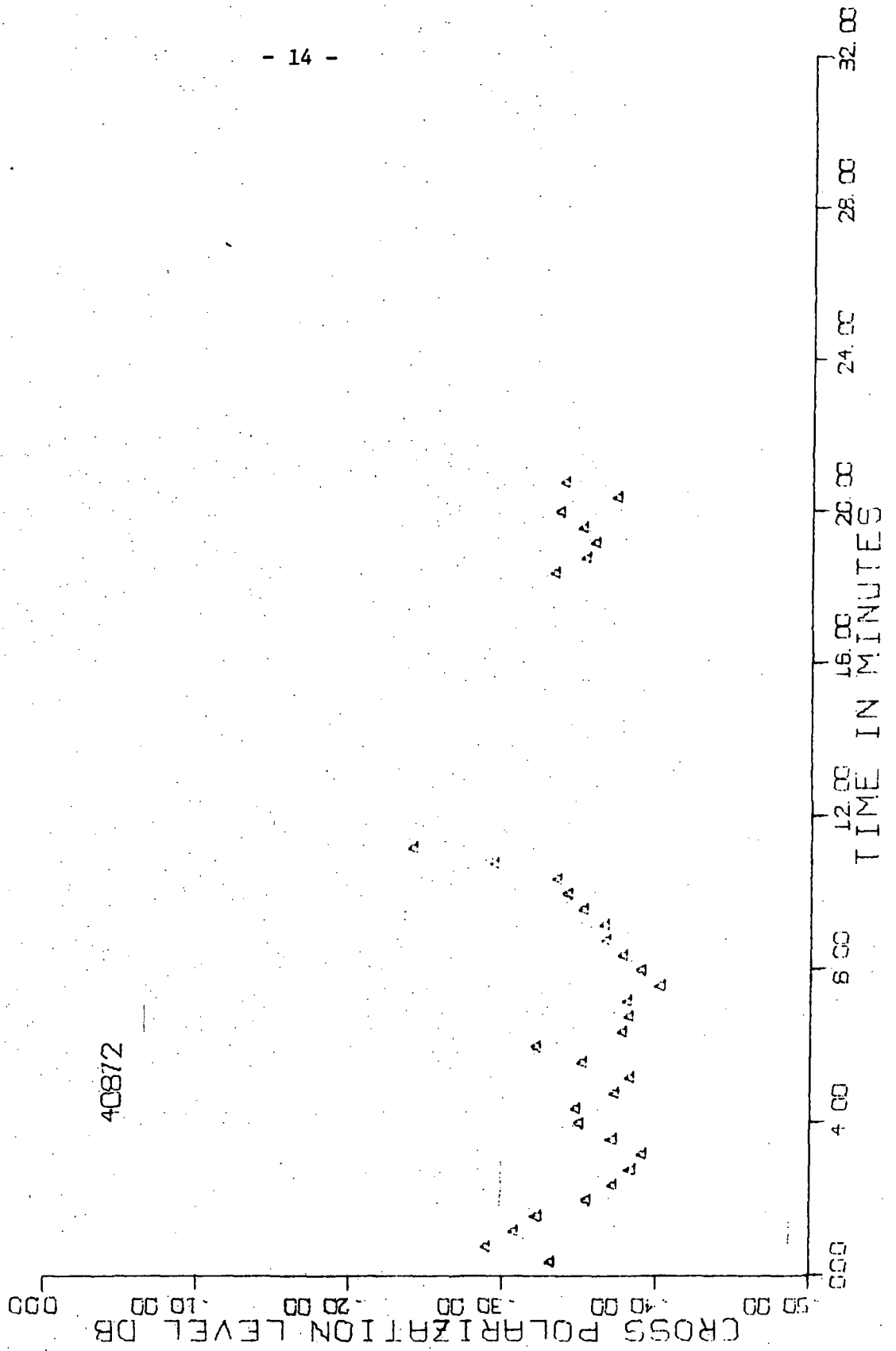
1. A plexiglass roof was installed above the receiving antenna on June 1, 1973. Prior to this date the receiving antenna had been exposed to the weather.
2. The receiver local oscillator was replaced on June 14, 1973.
3. On June 27, 1973, the mode 0 switching time (see page 3) was changed from four seconds to 10 seconds to facilitate some phase measurements. The sampling rate was unchanged.

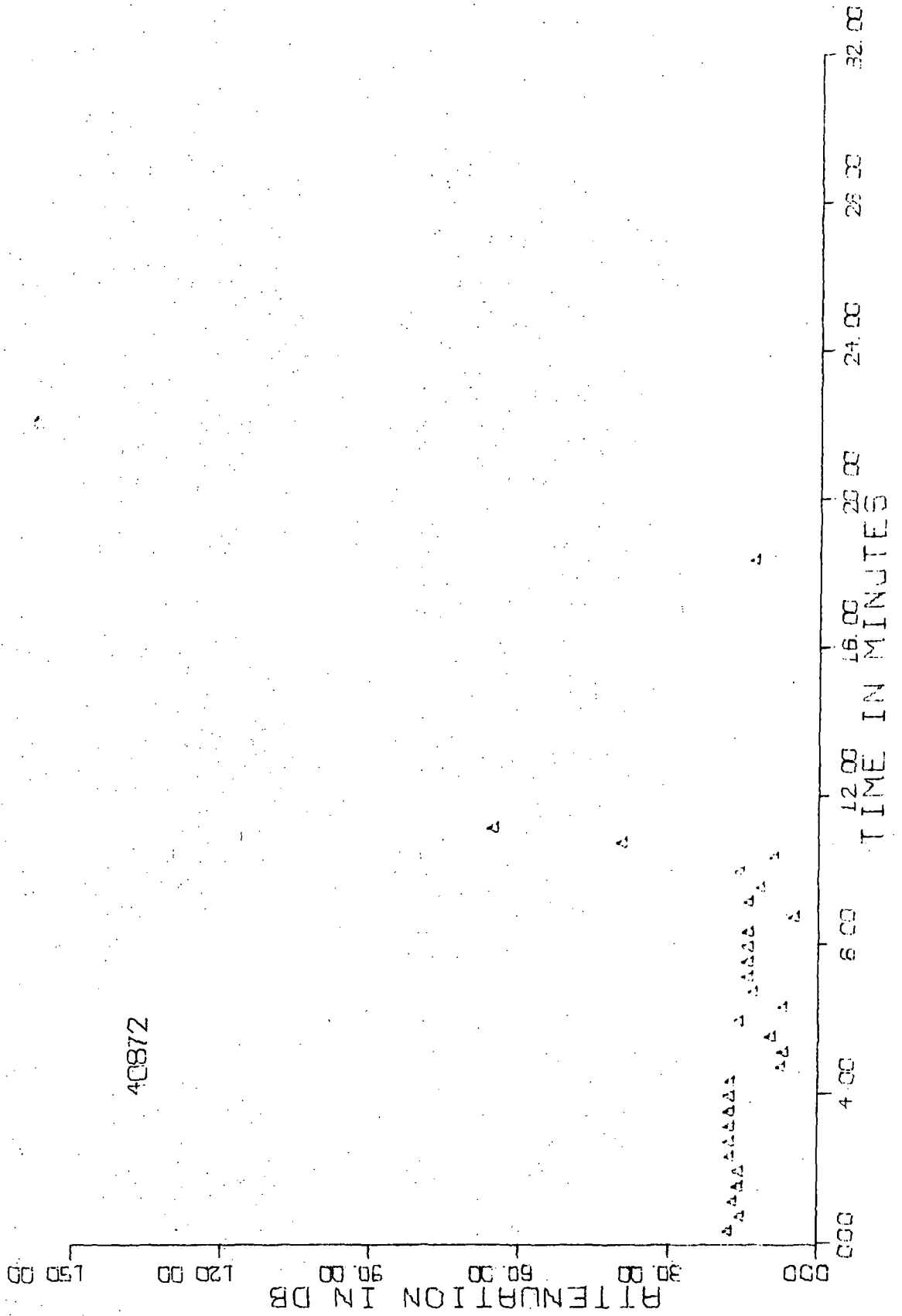
Except for these minor changes, the data for all storms were taken under essentially the same conditions.

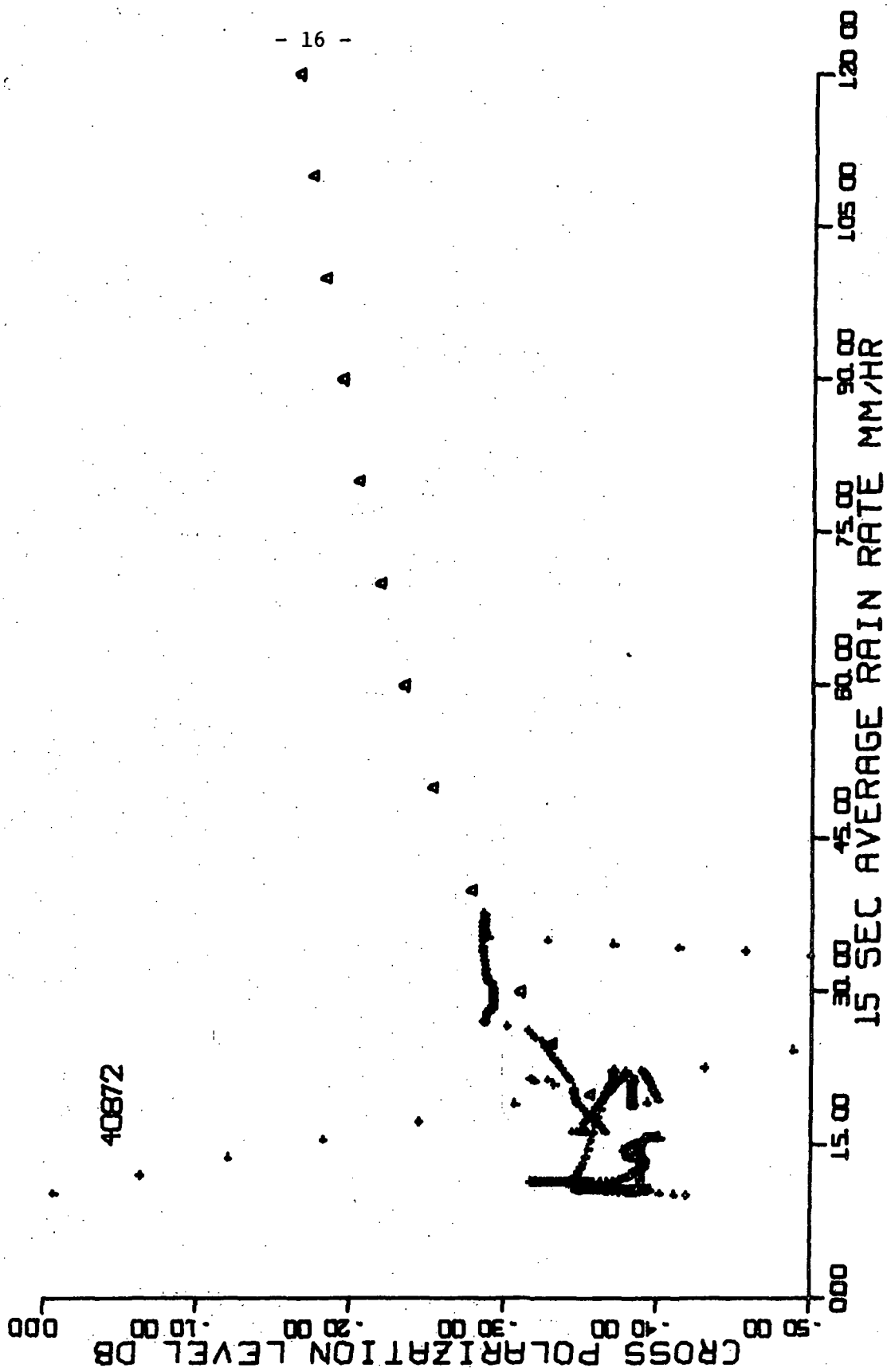
5. Acknowledgements

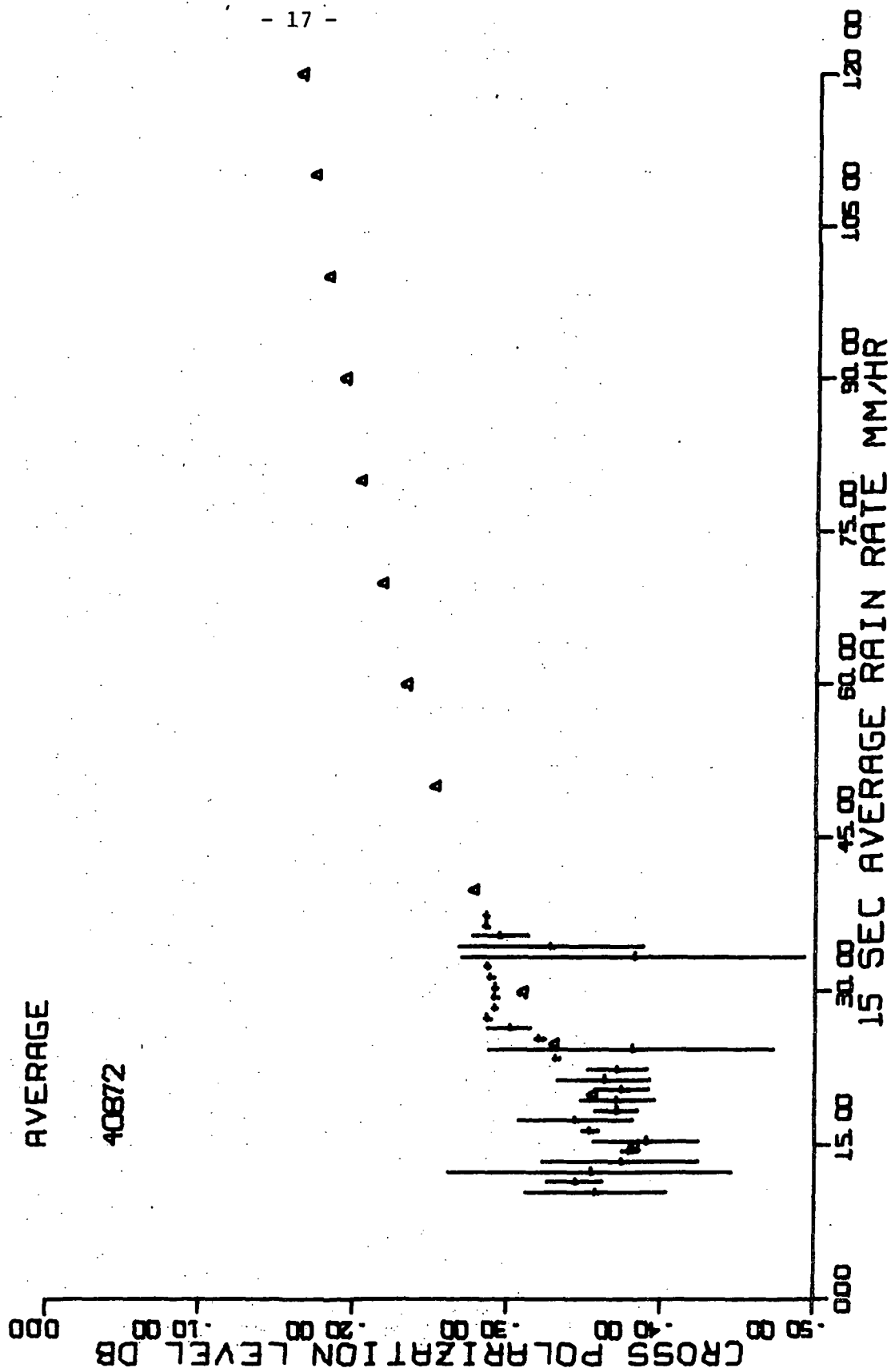
The authors wish to thank Sherida F. Battrell and Harlow N. Pendrak for their contributions to this report. Mr. Pendrak wrote the computer program which generated the time-history plots, and Mrs. Battrell typed the report and supervised its assembly.











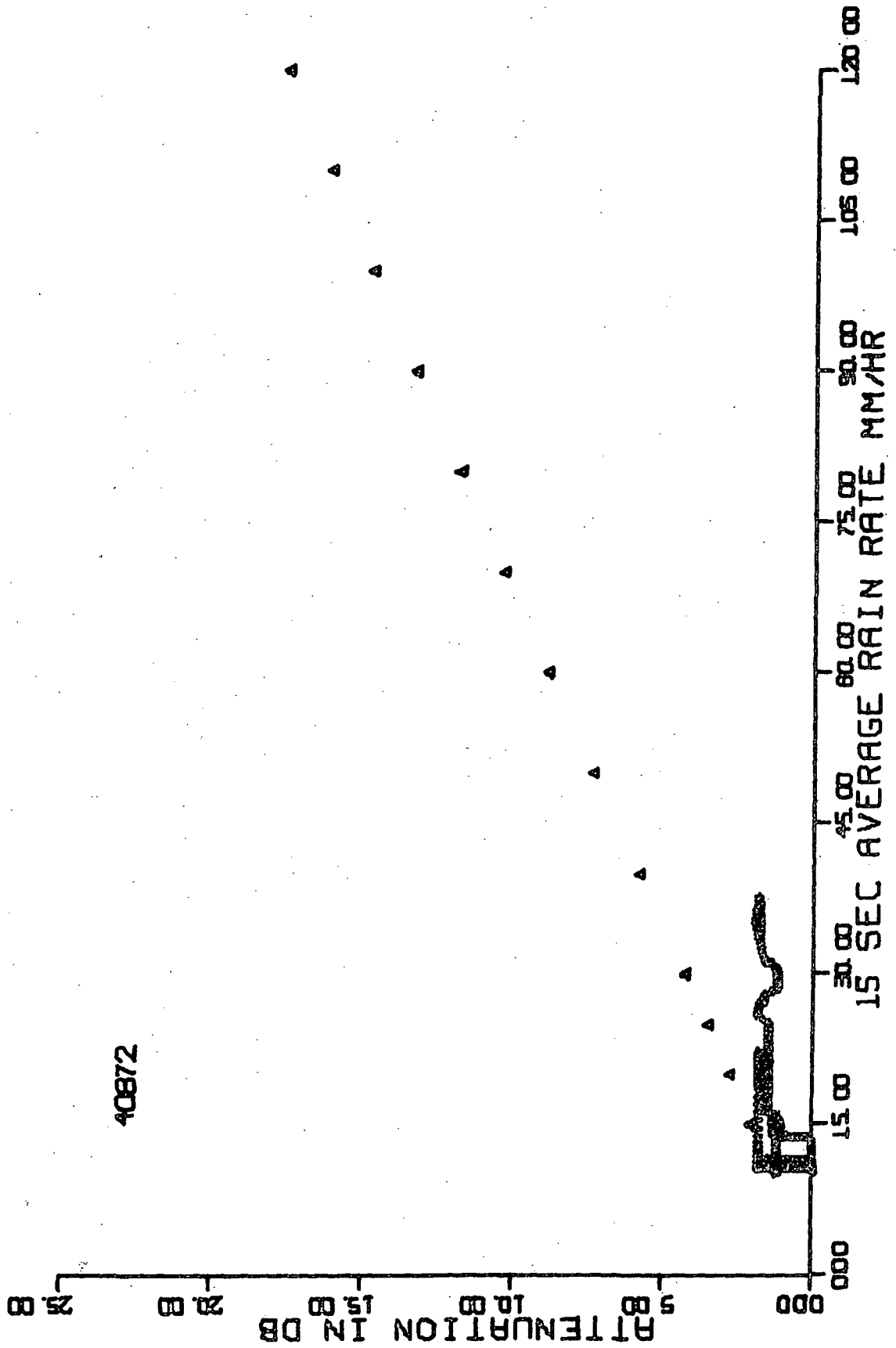
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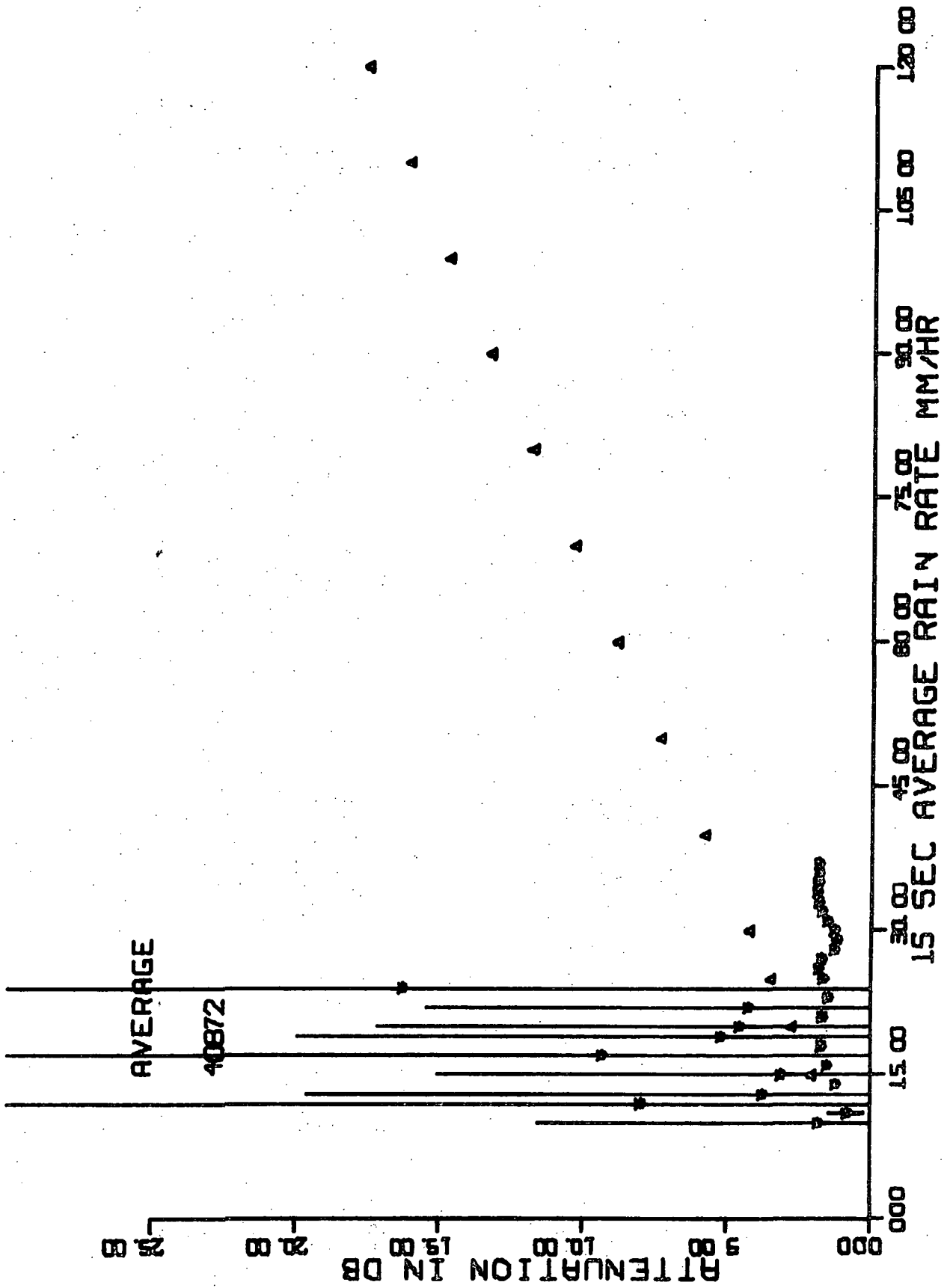
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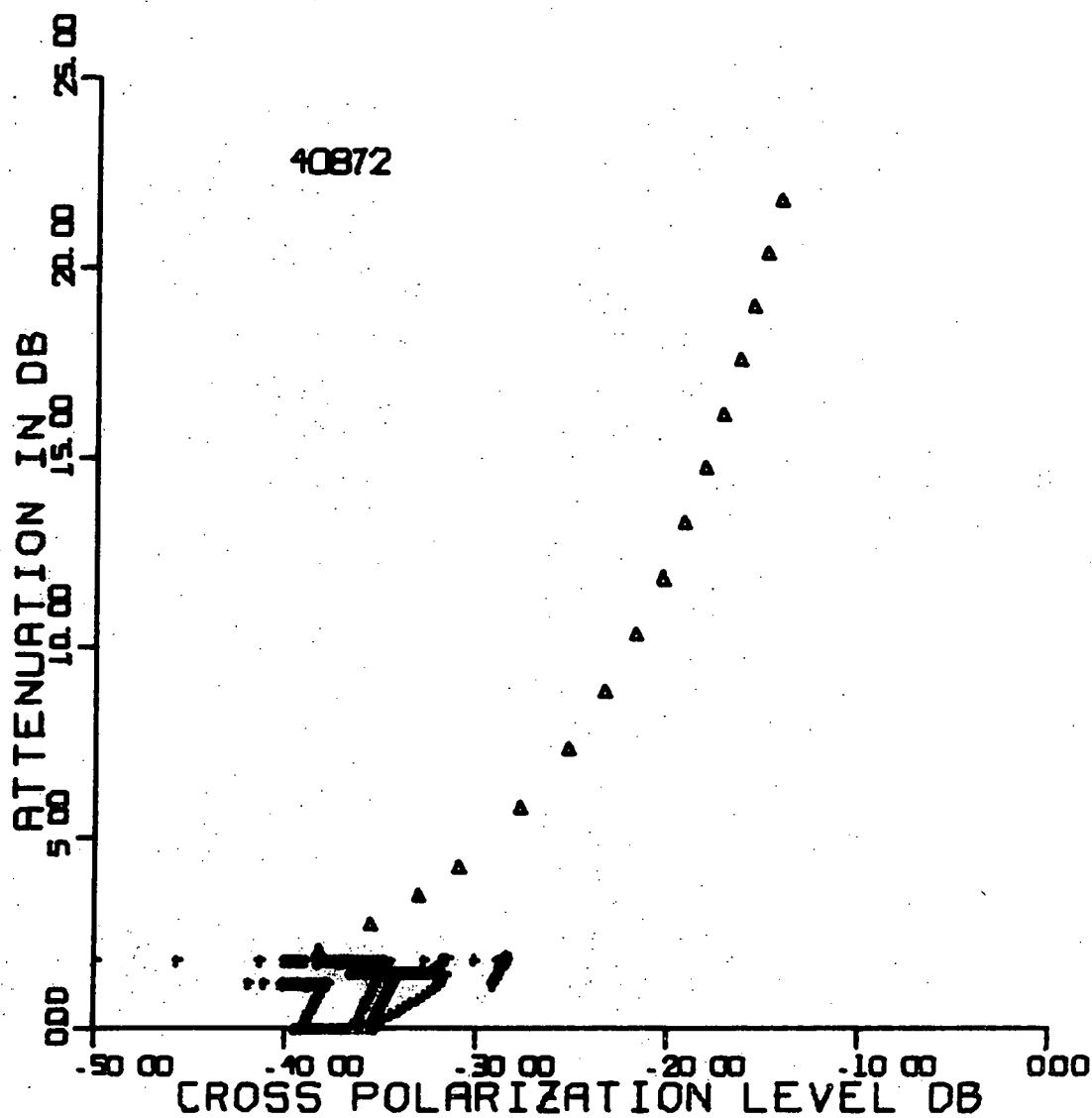
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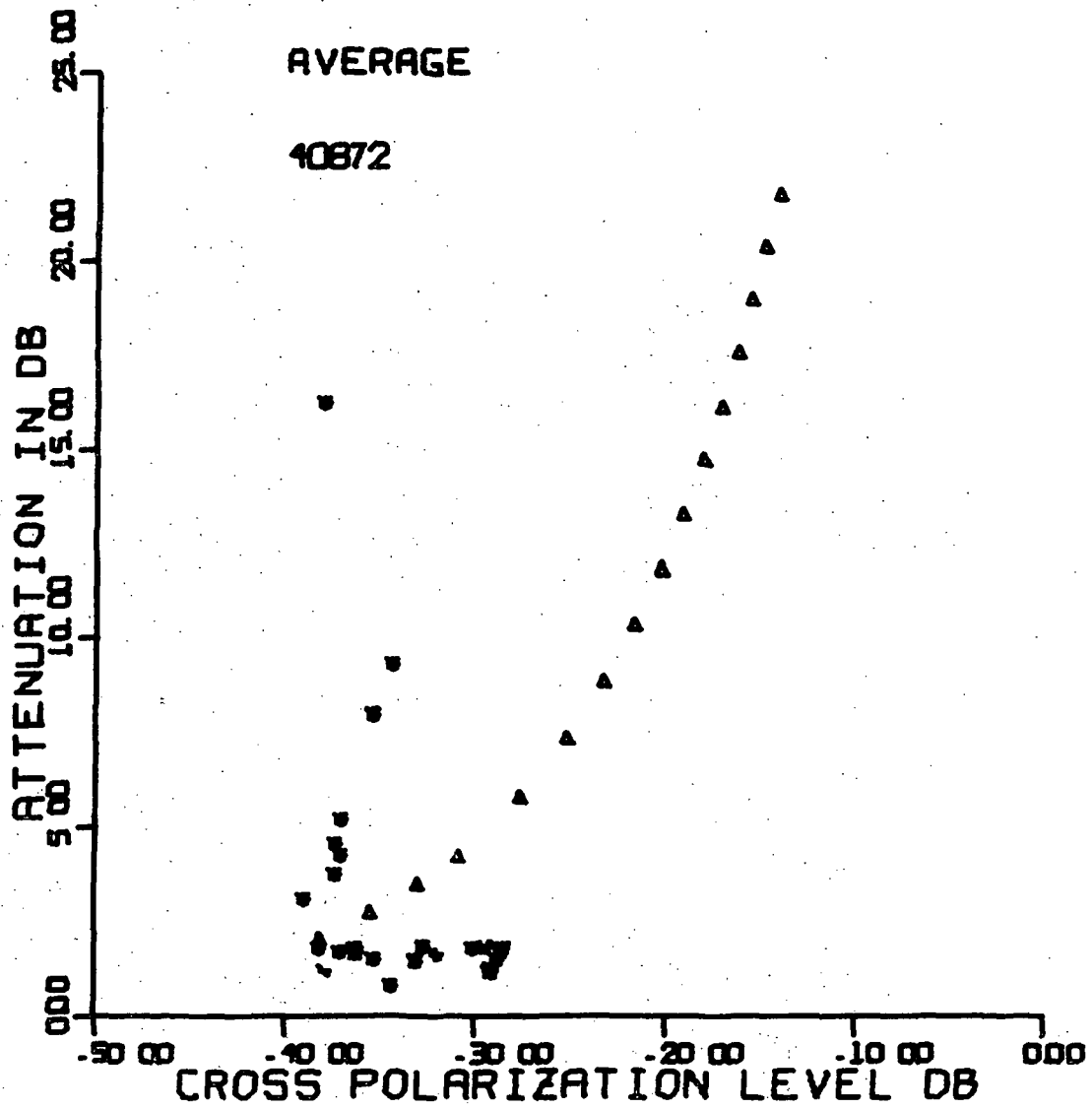
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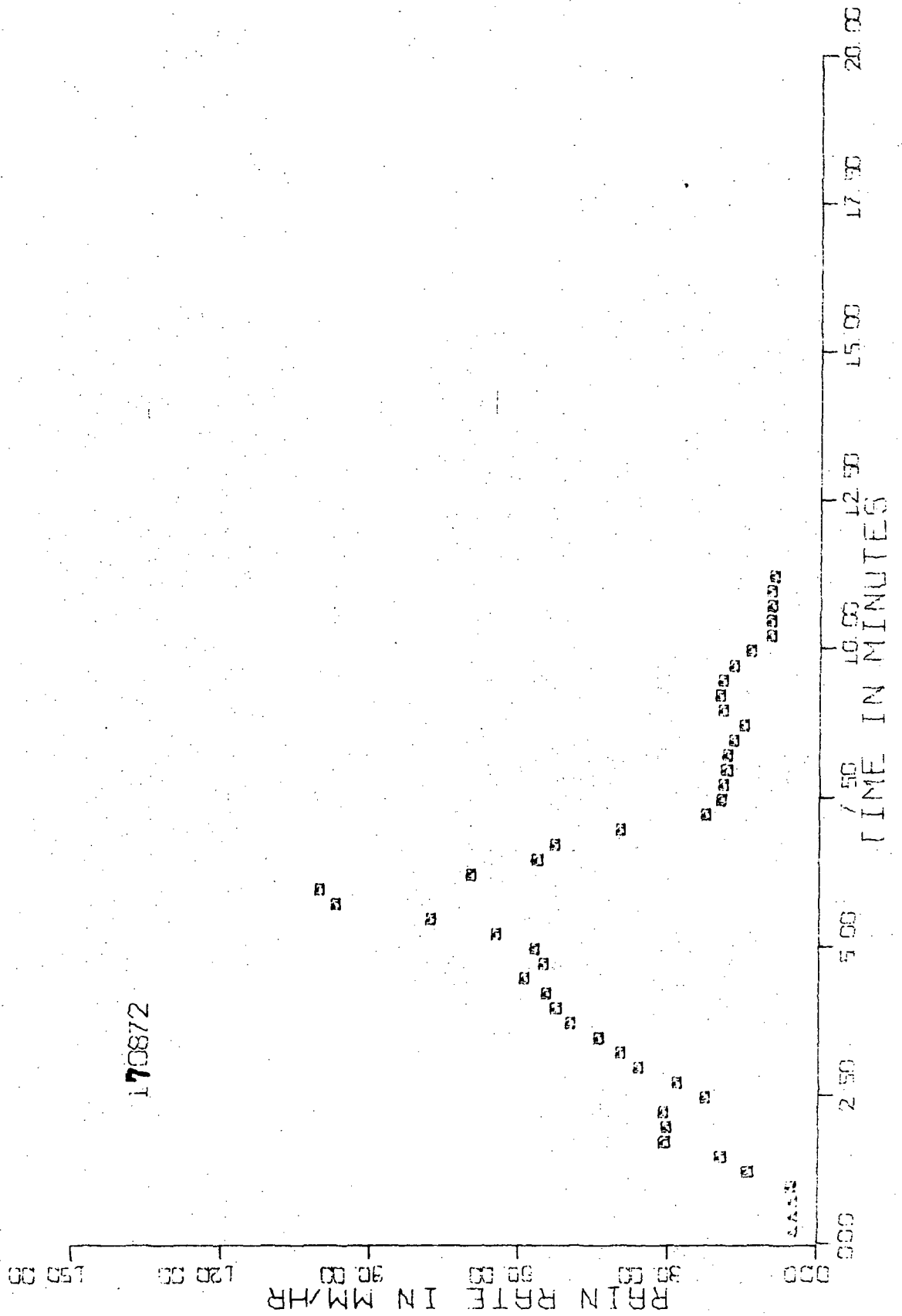
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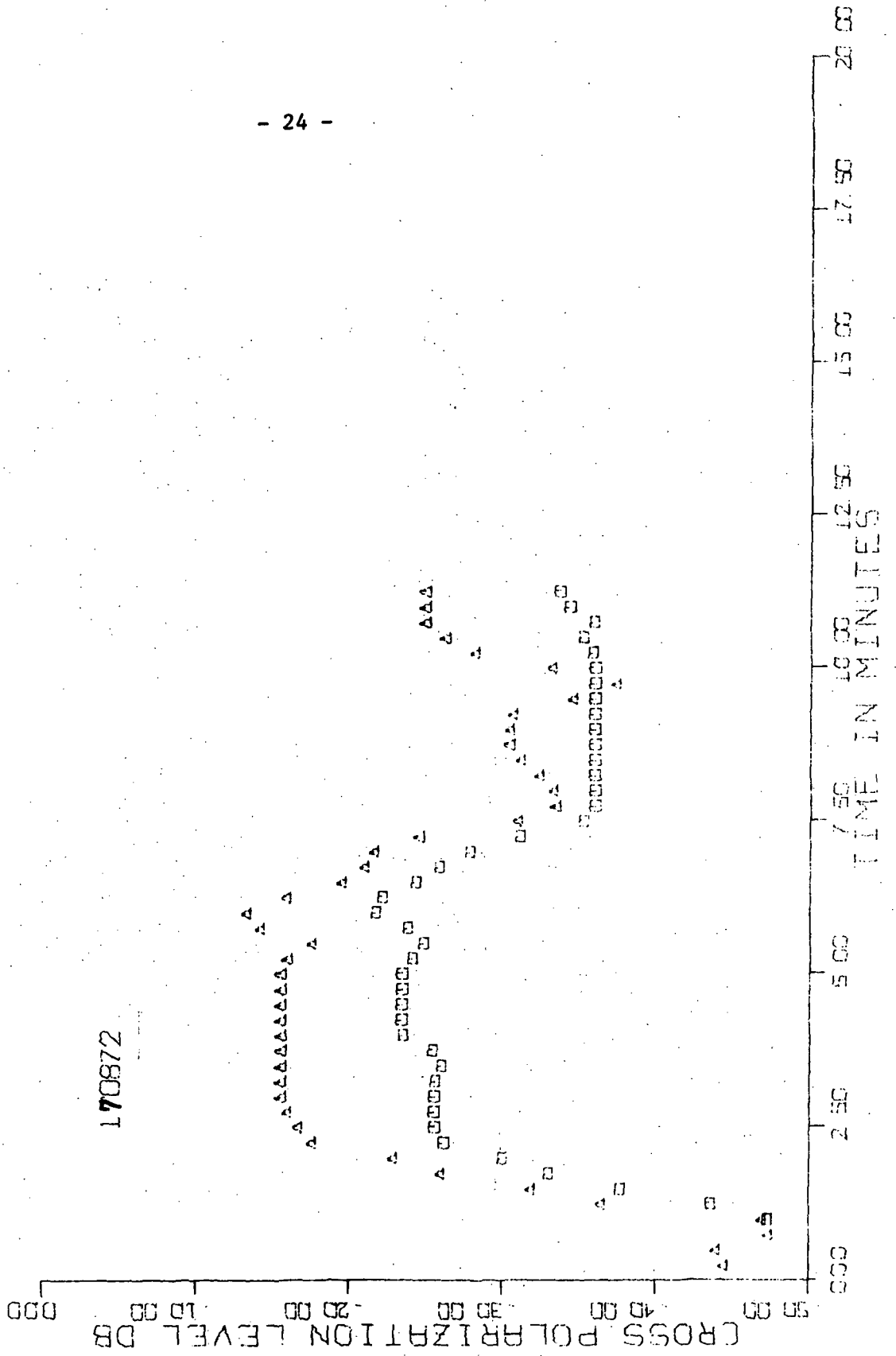


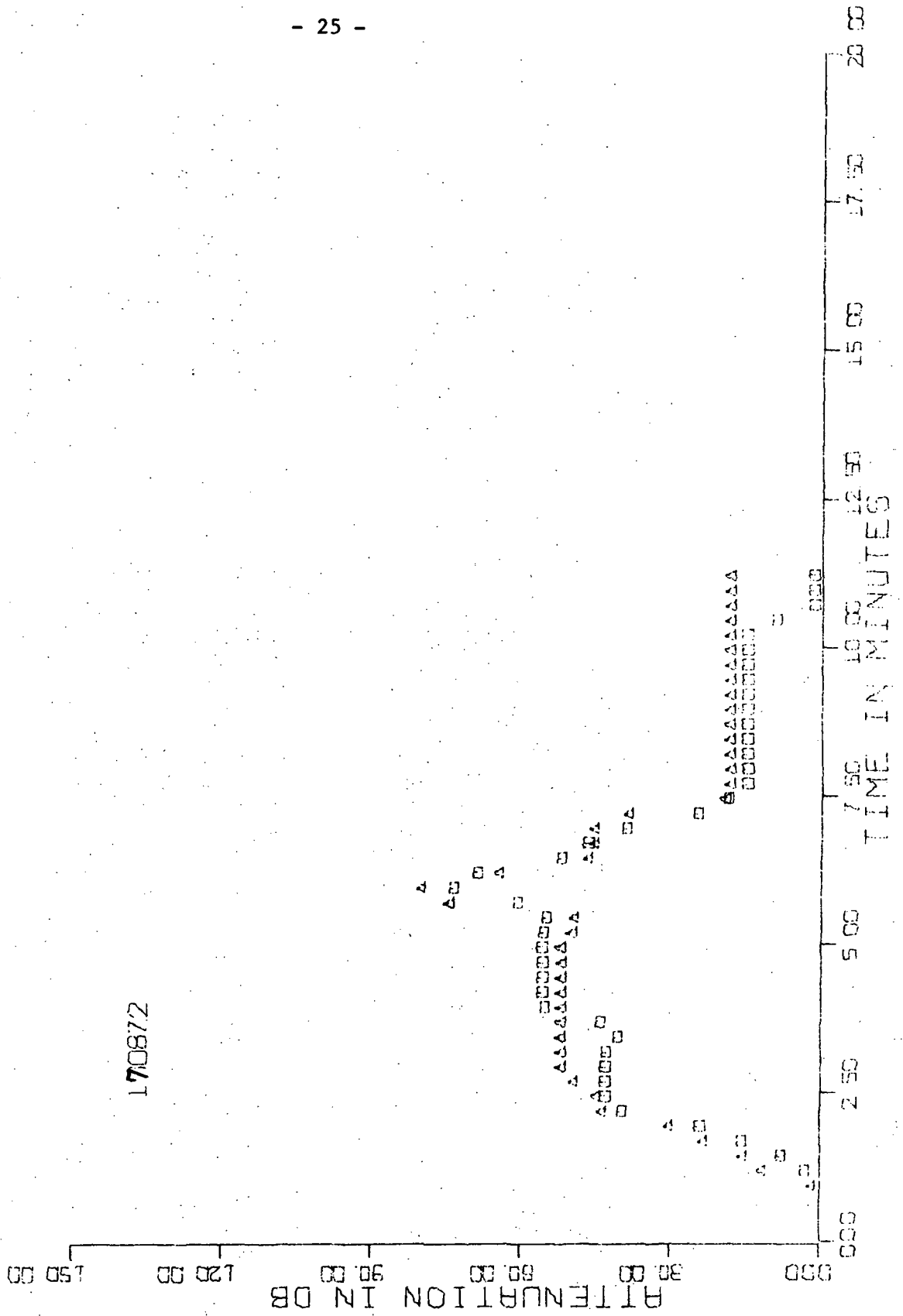


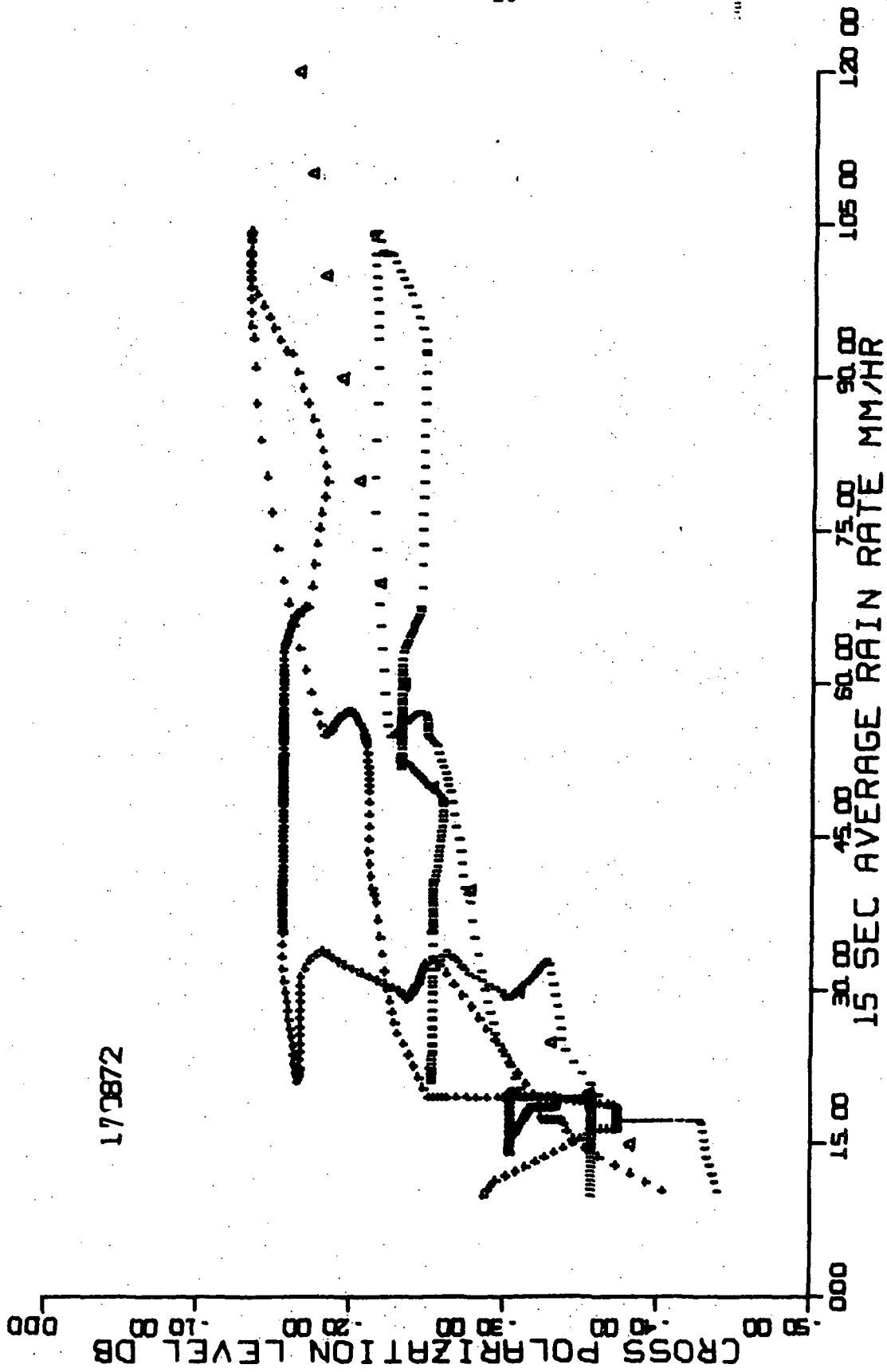


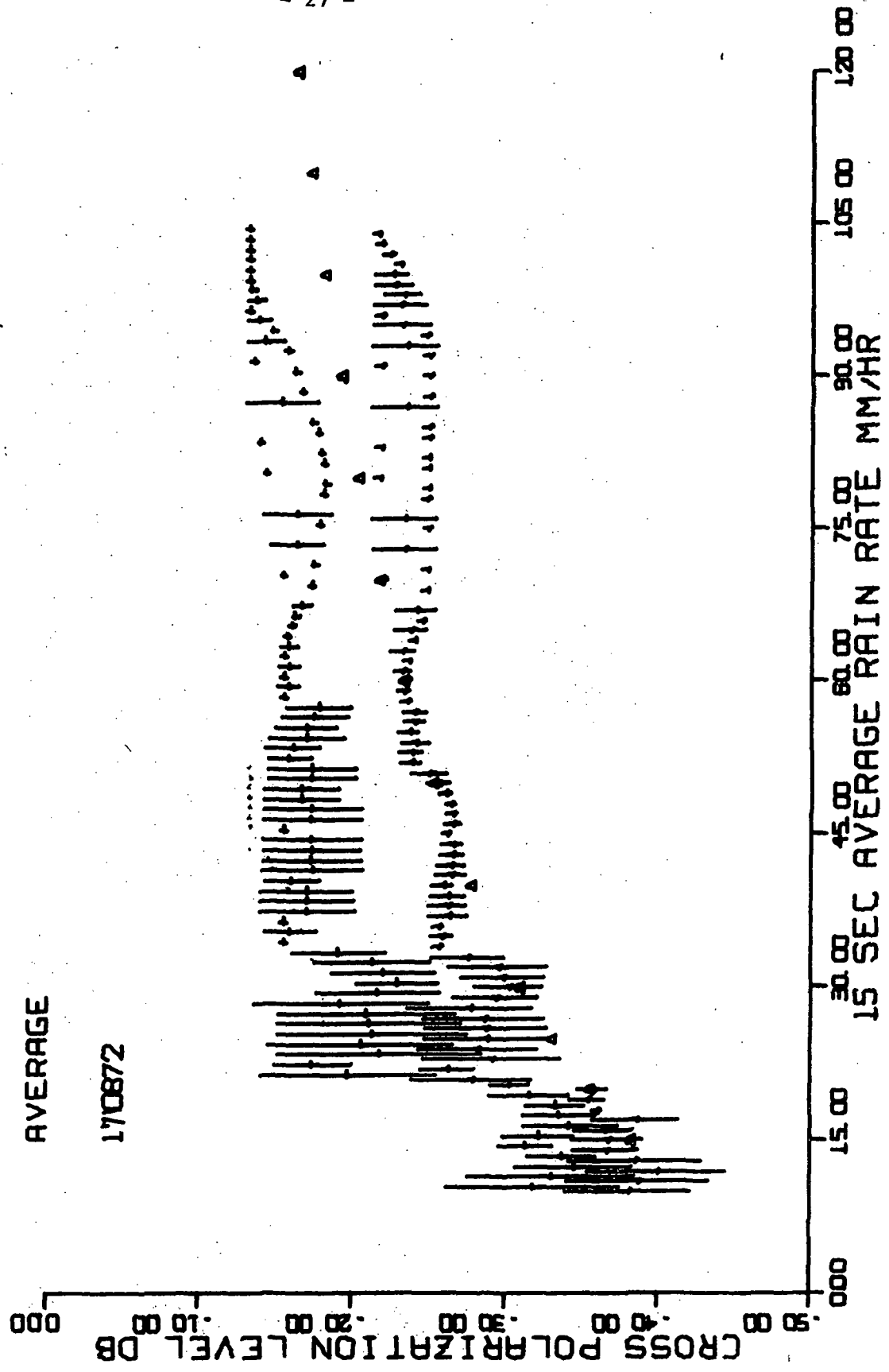


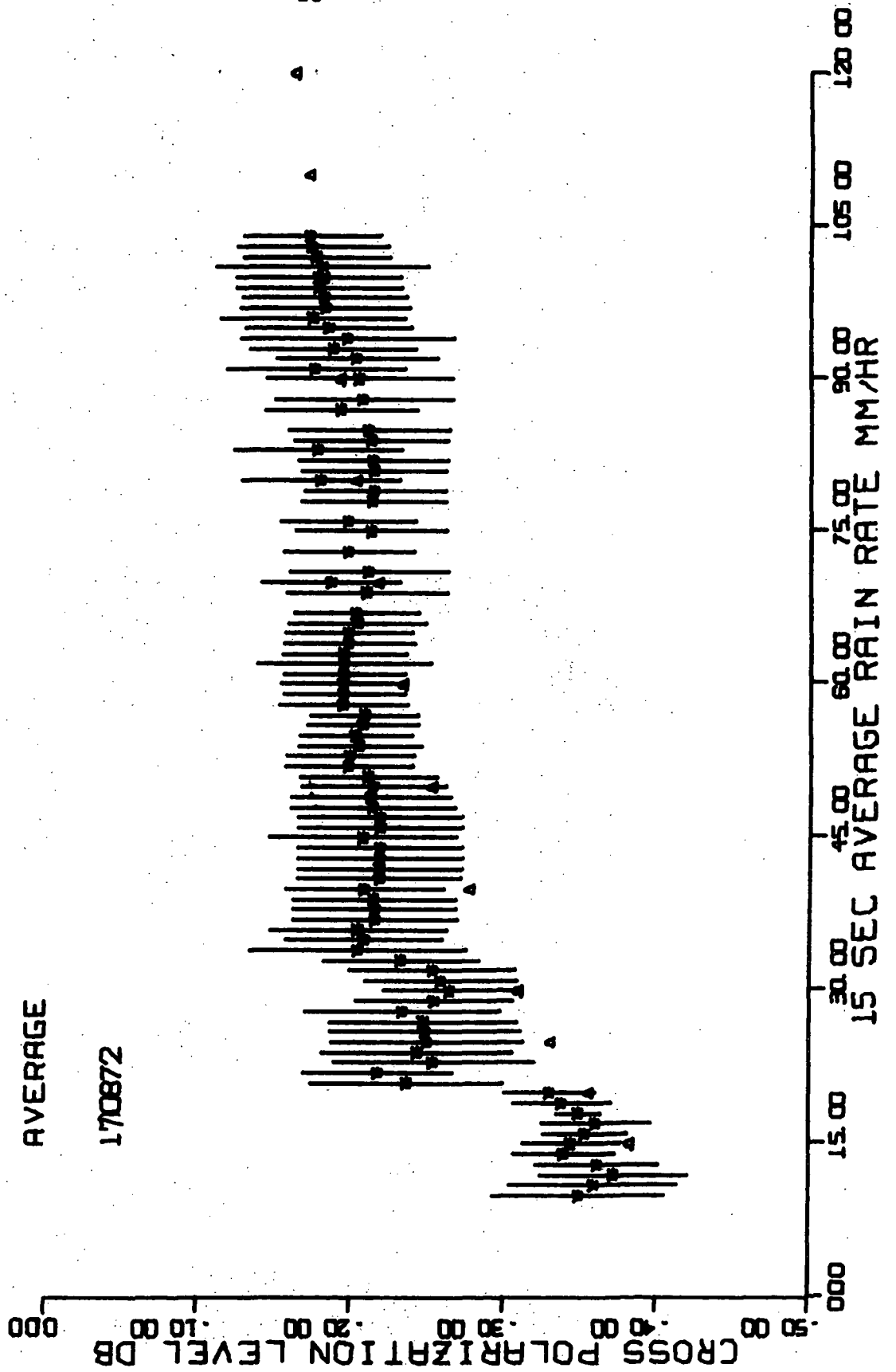


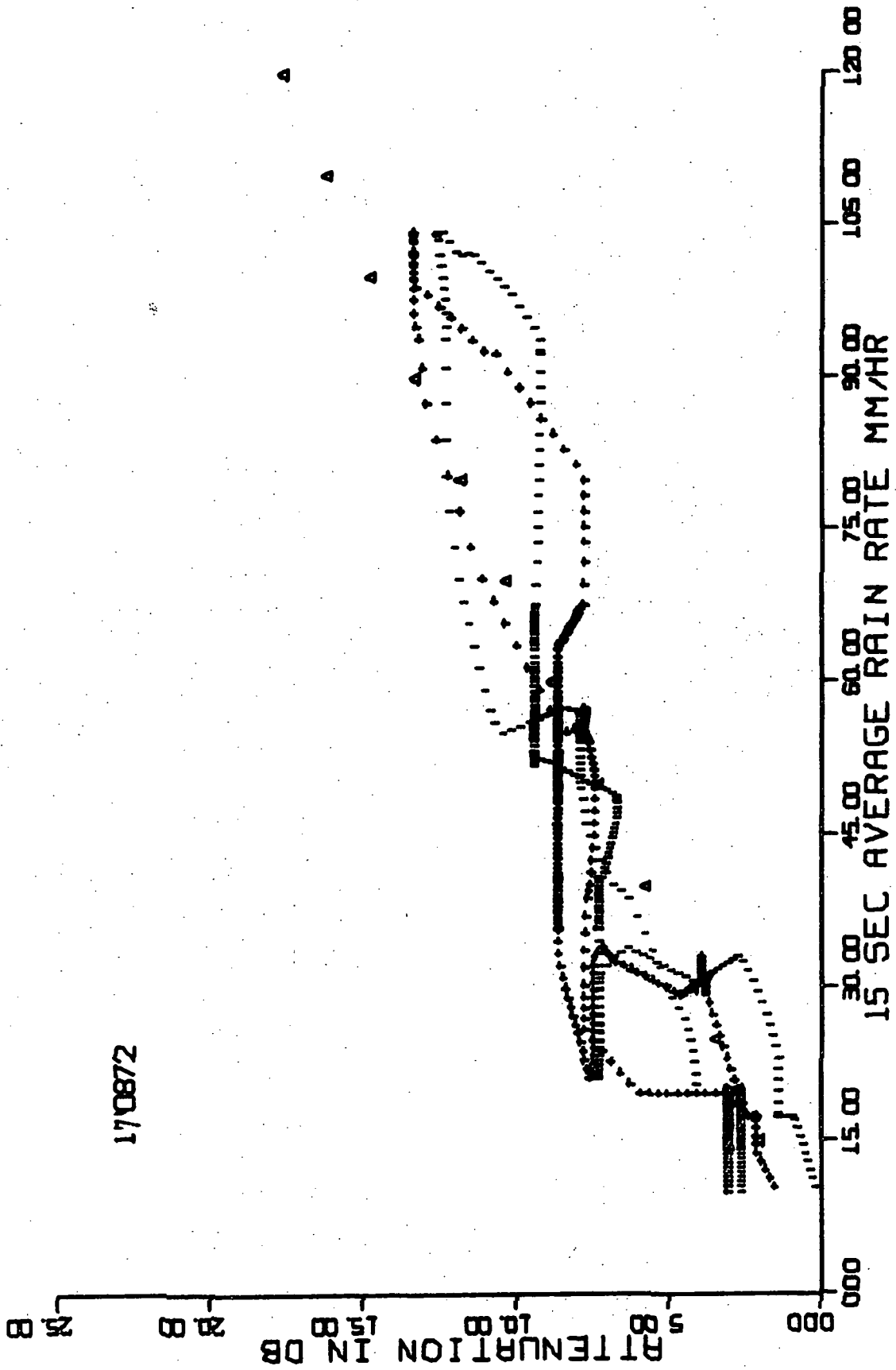


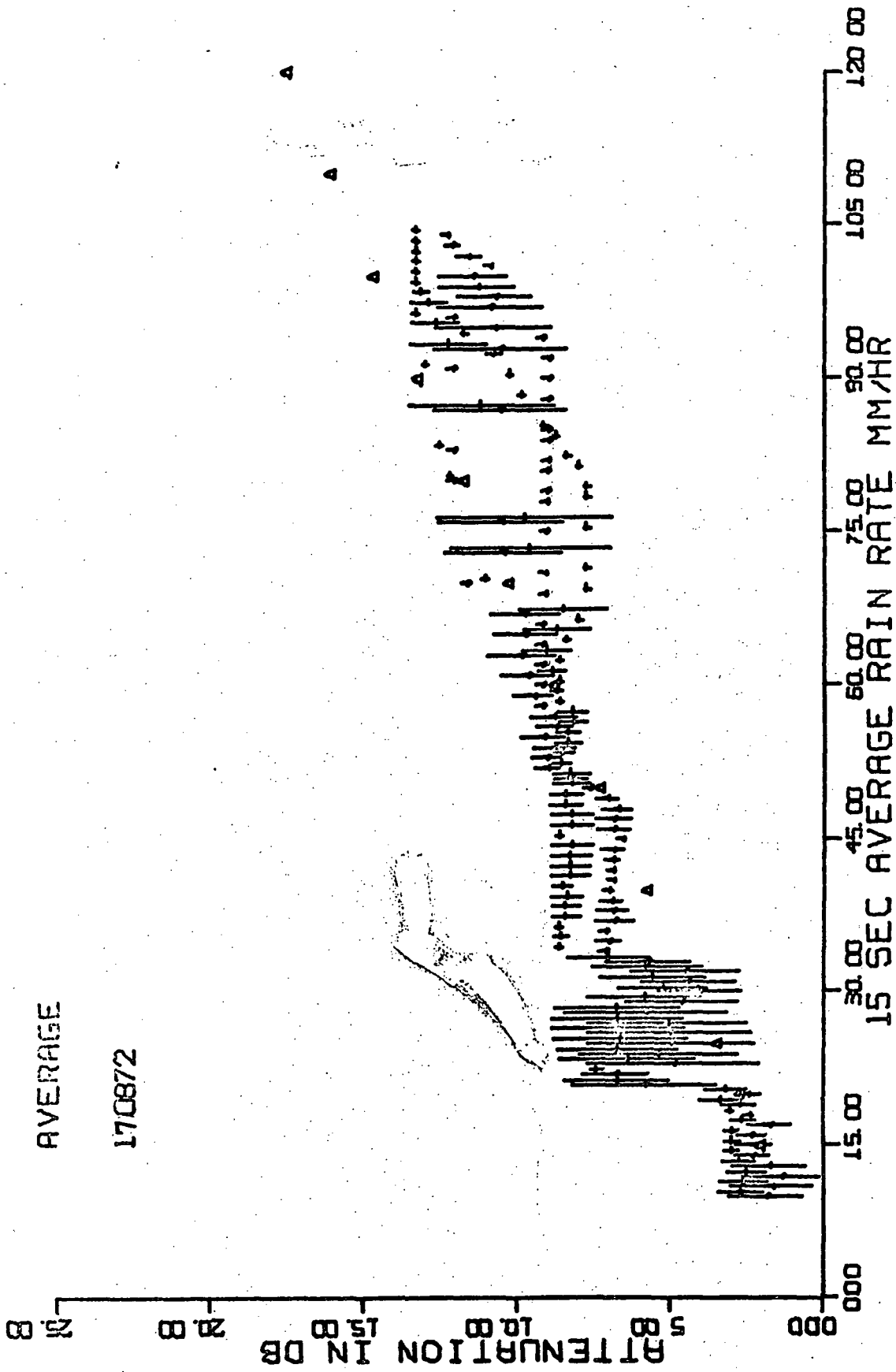


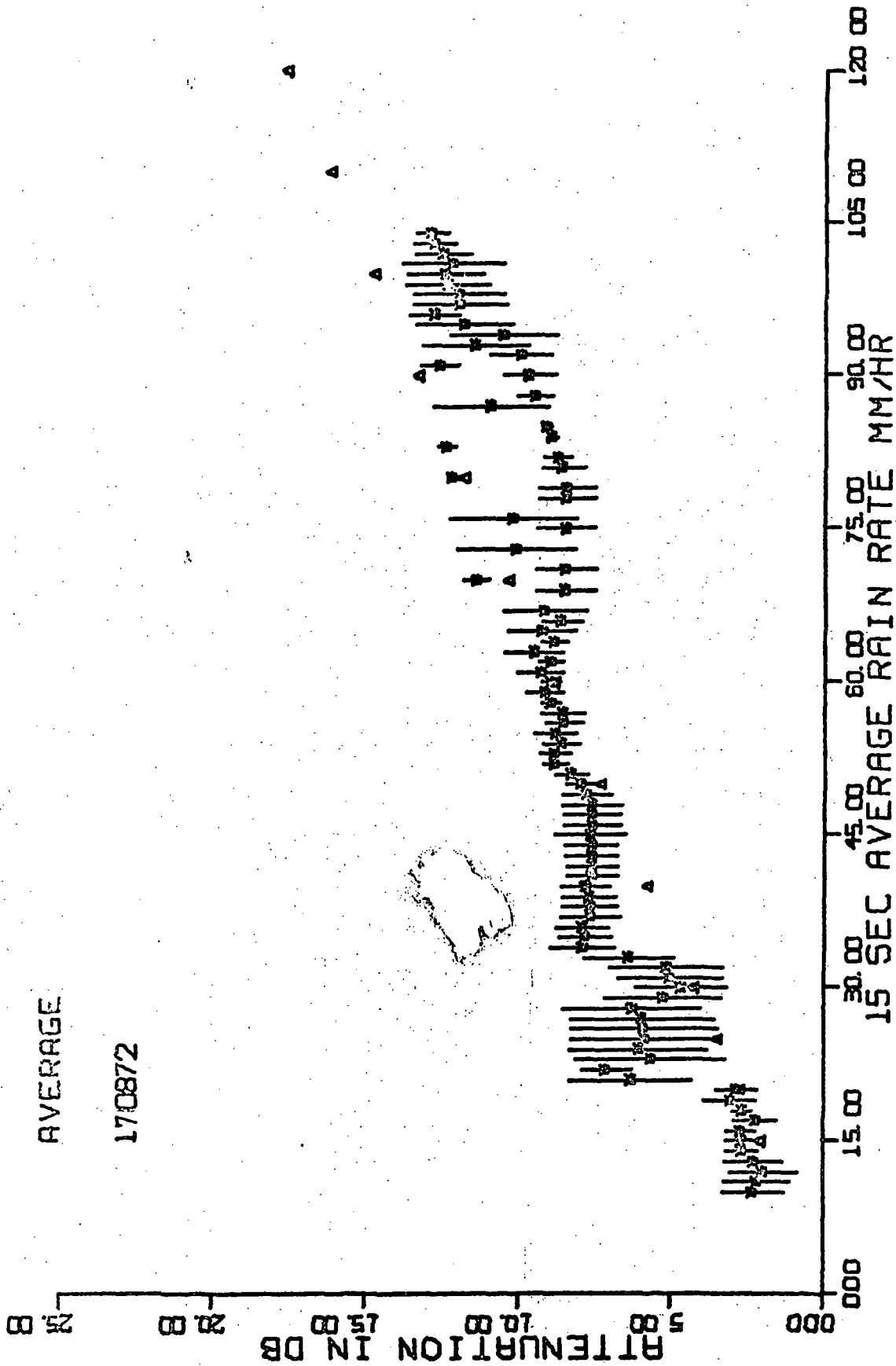


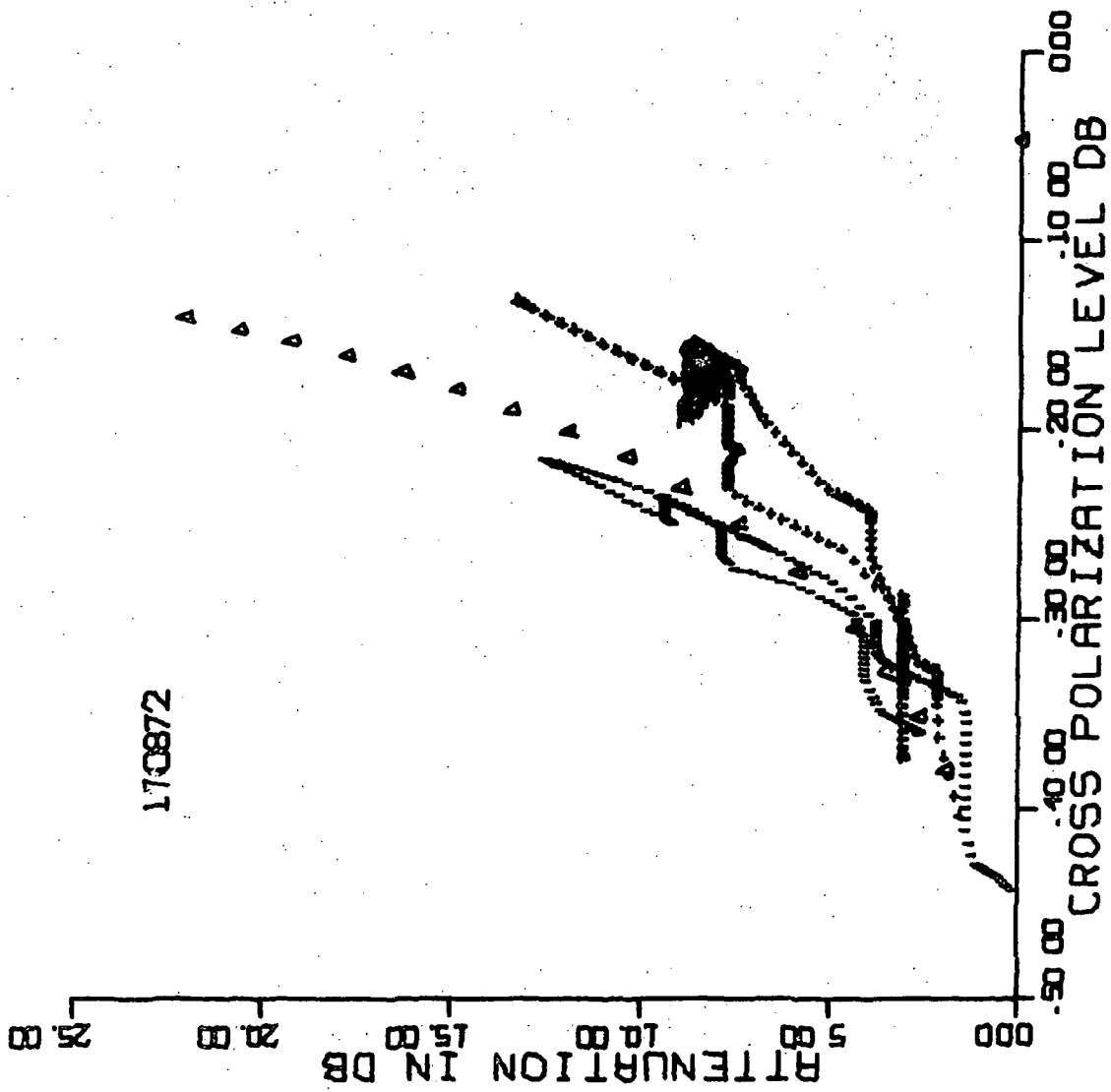


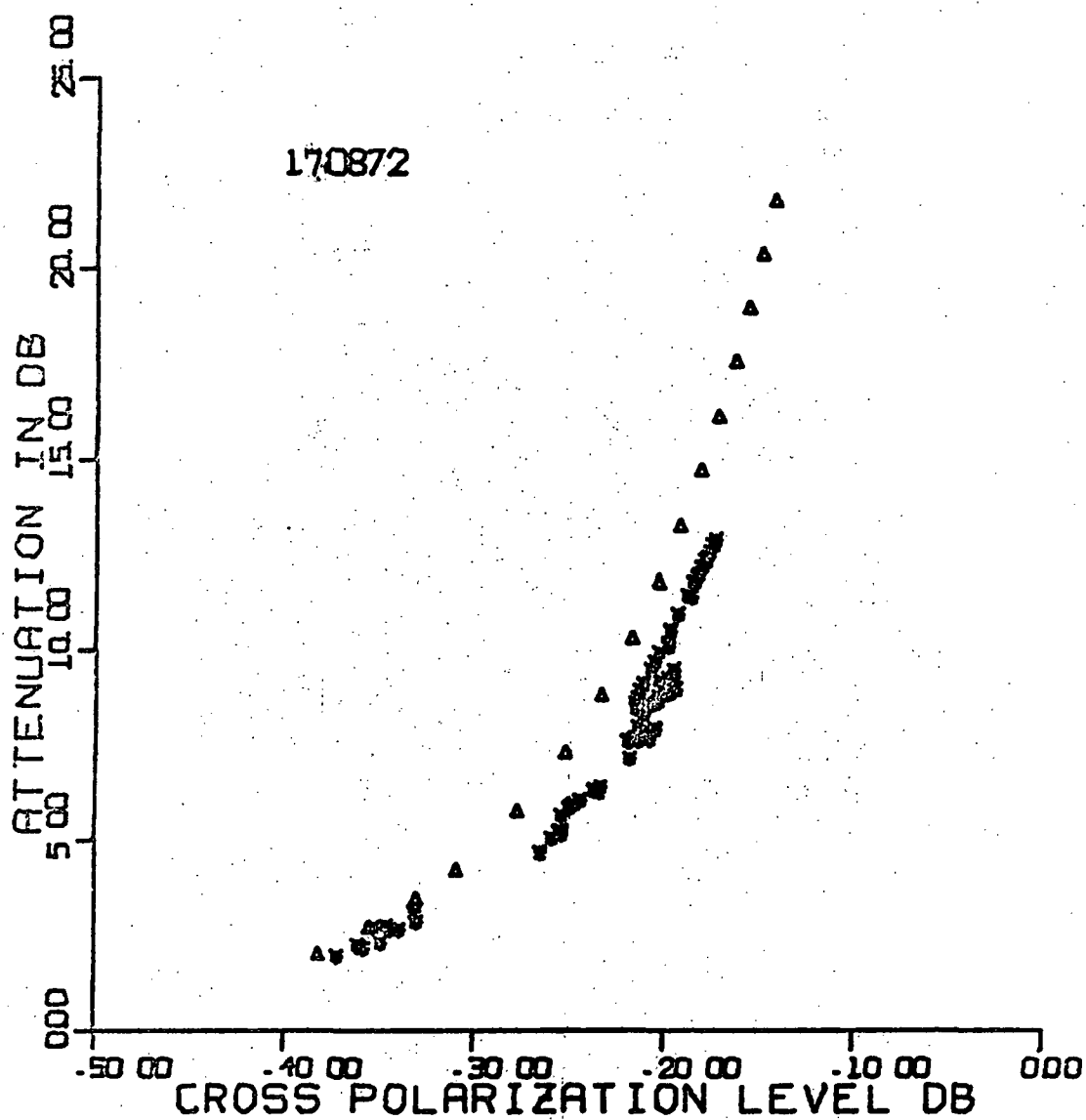


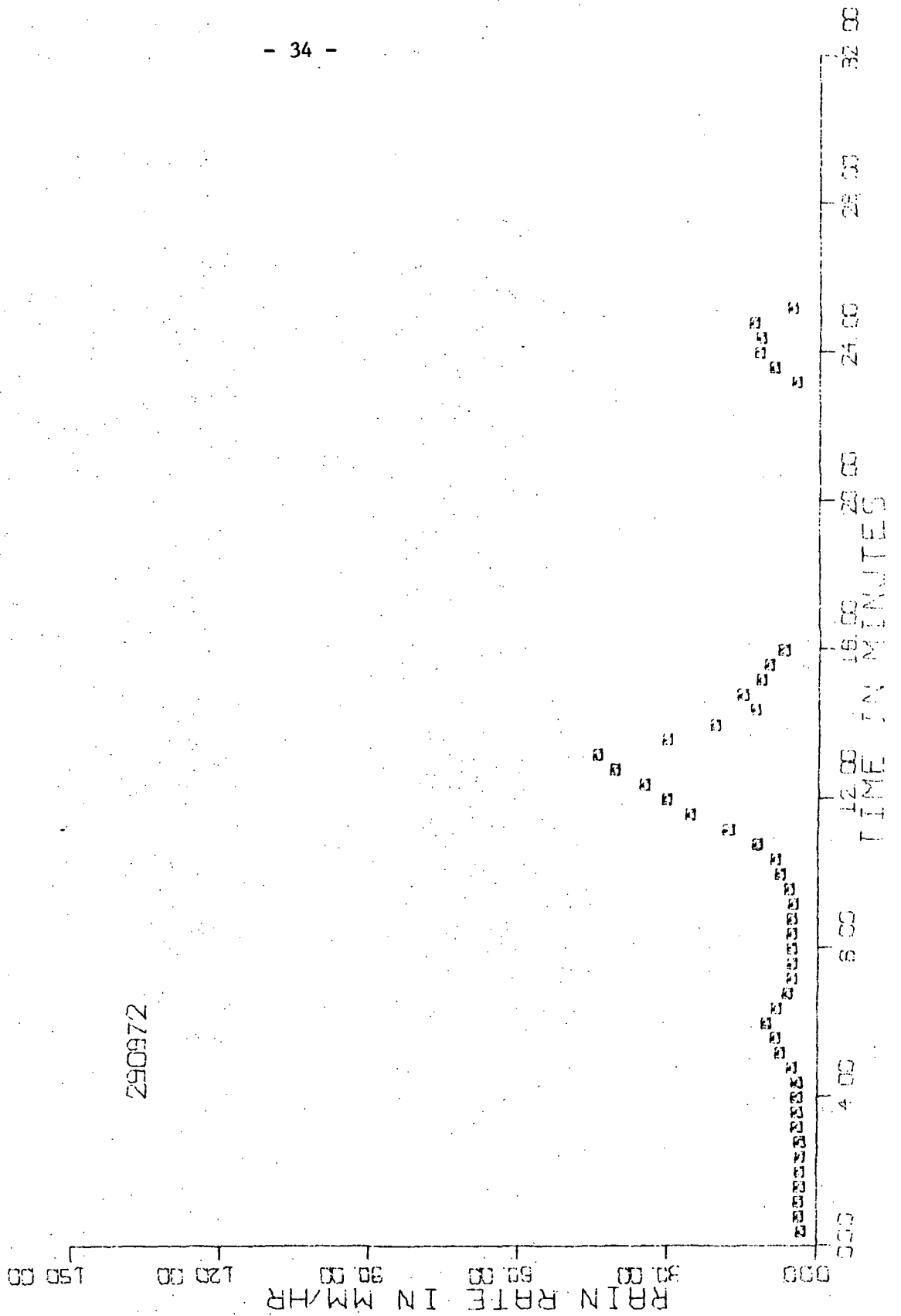


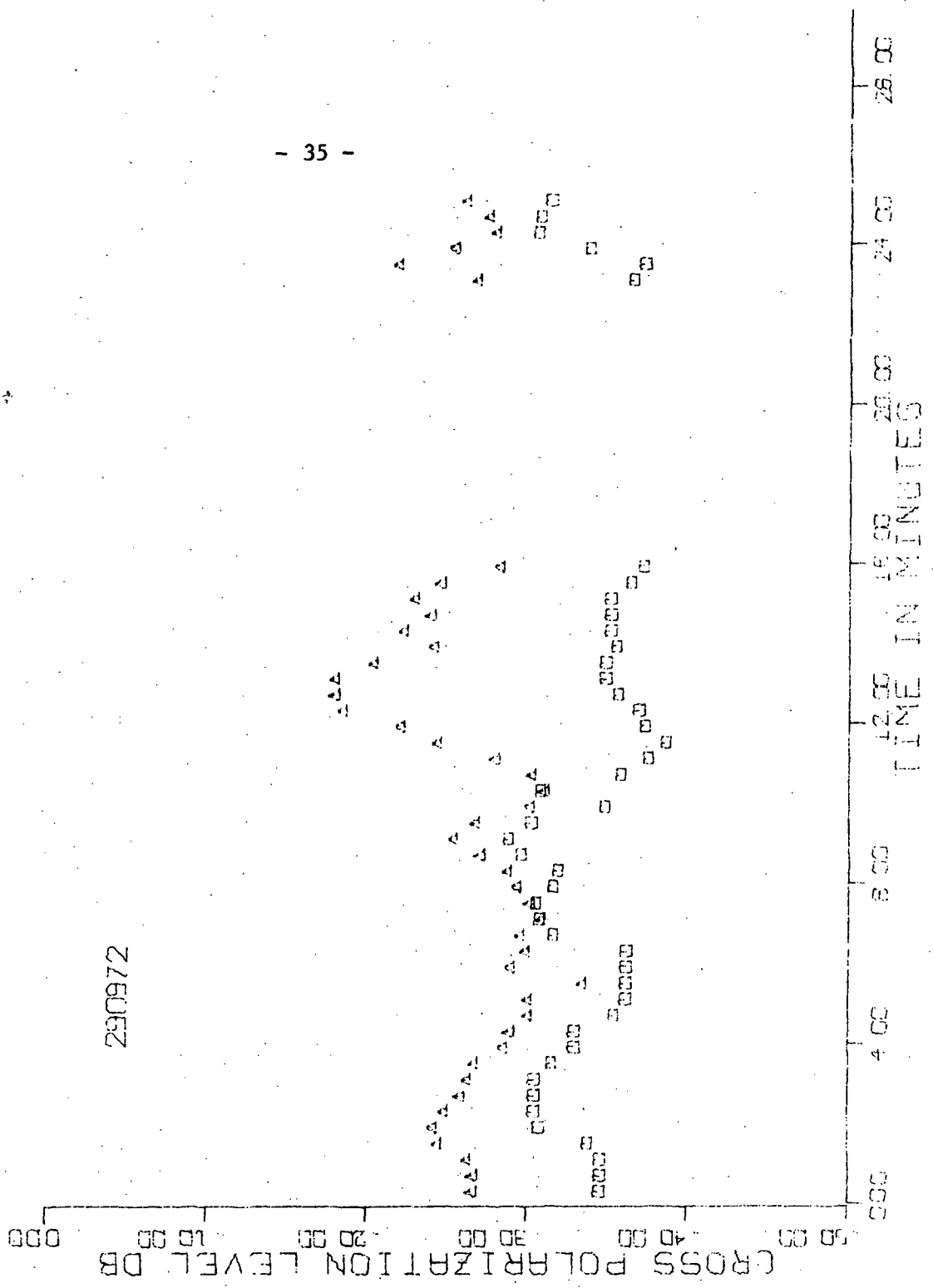


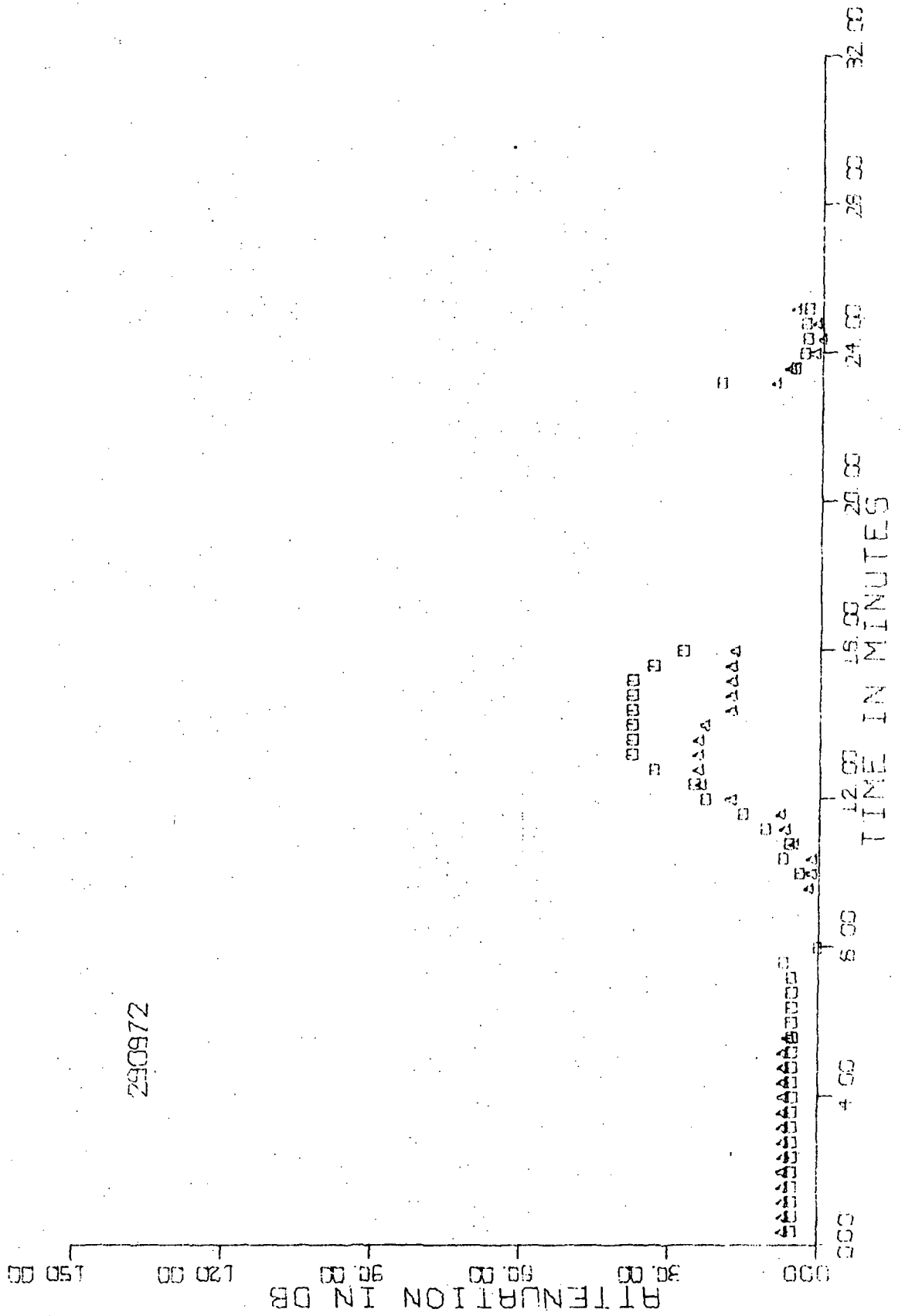


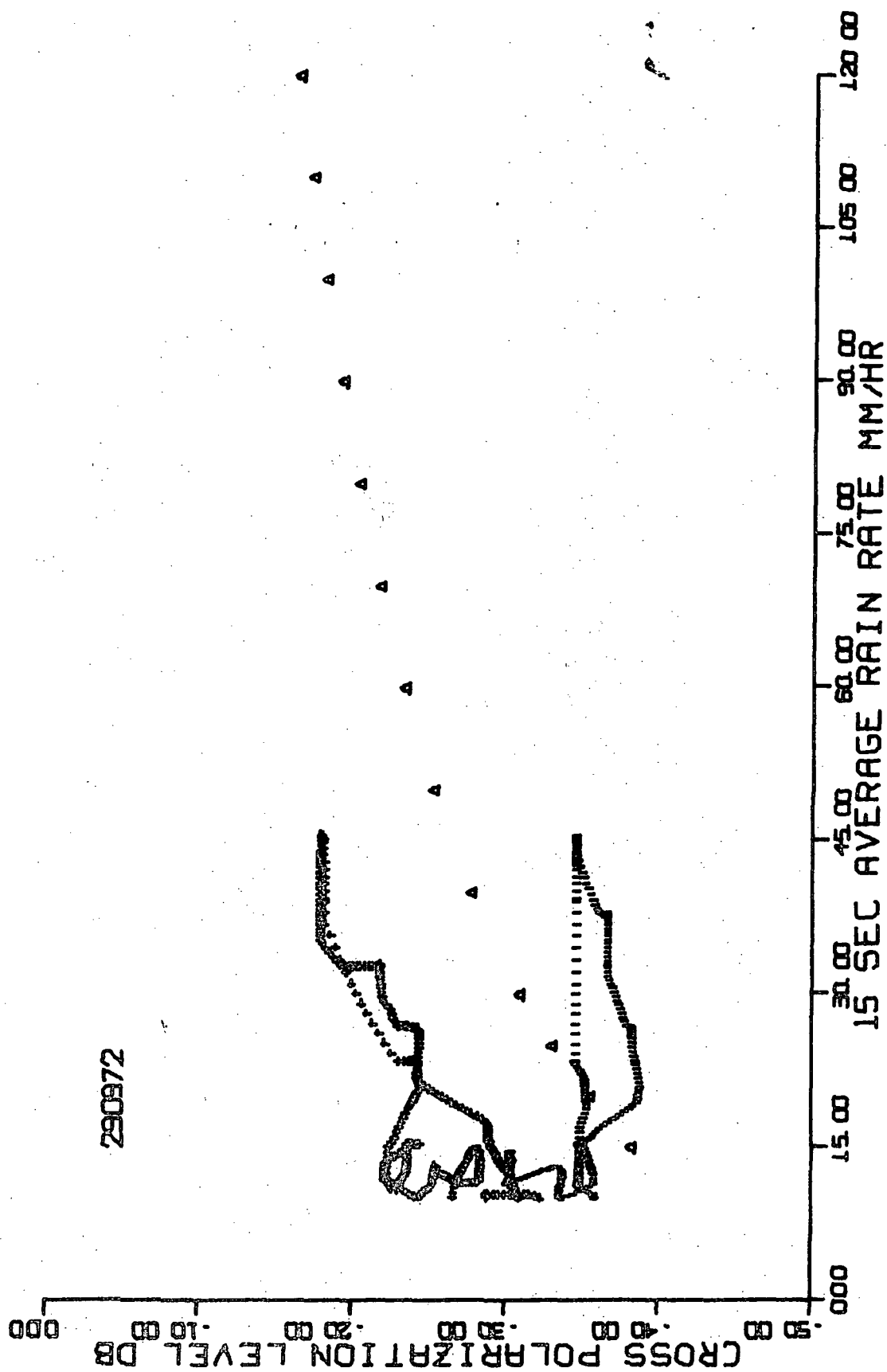


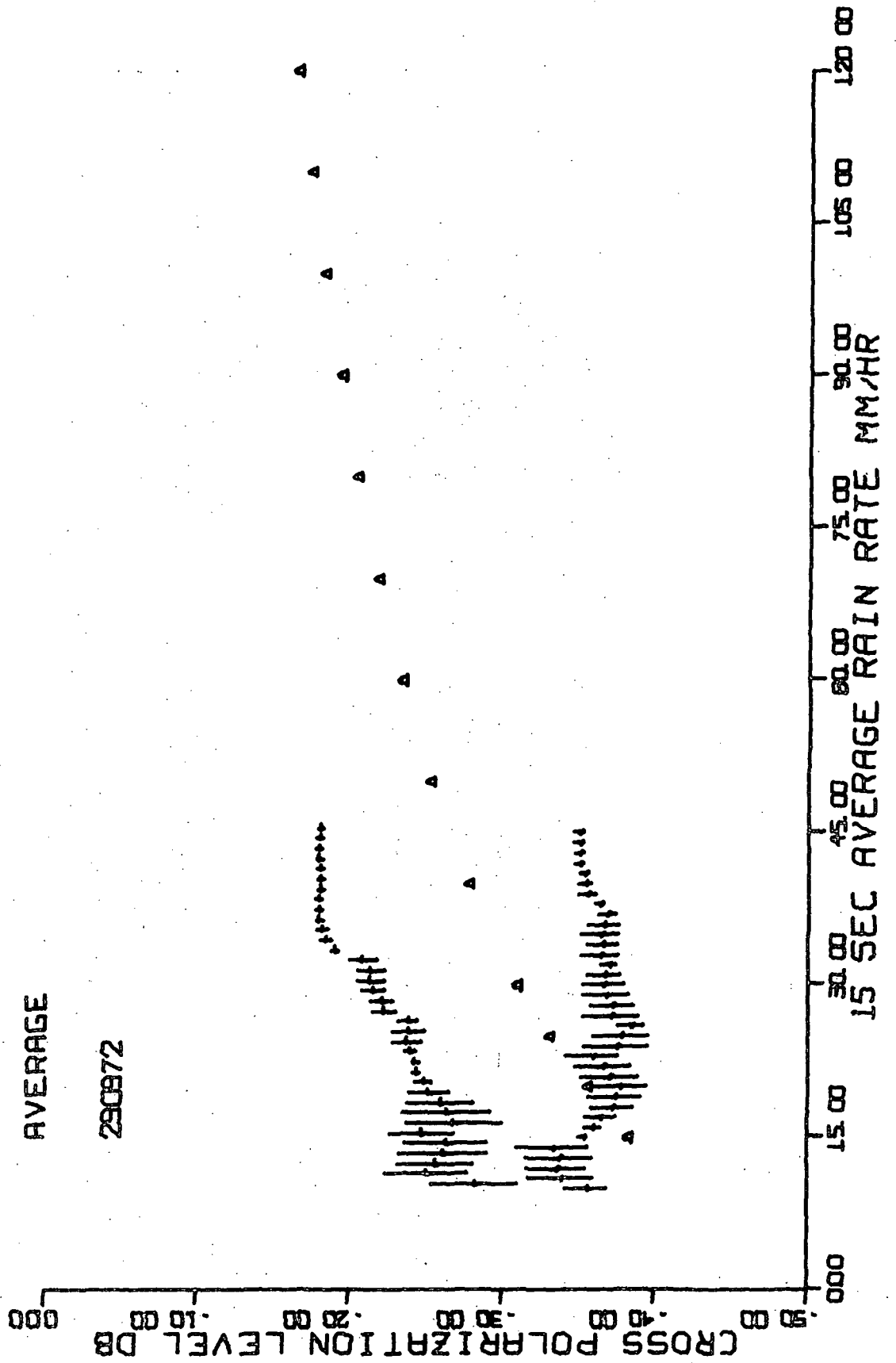


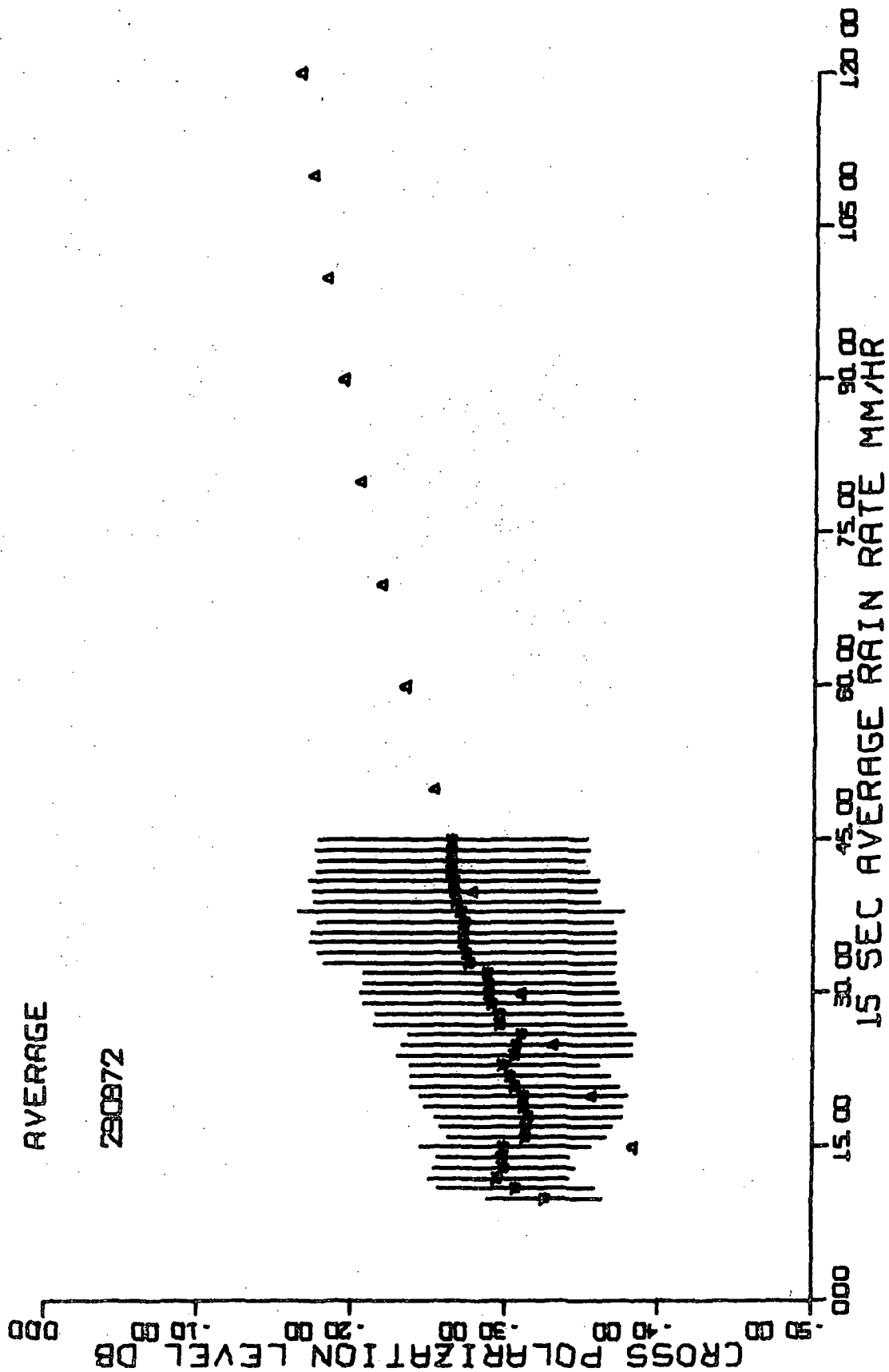


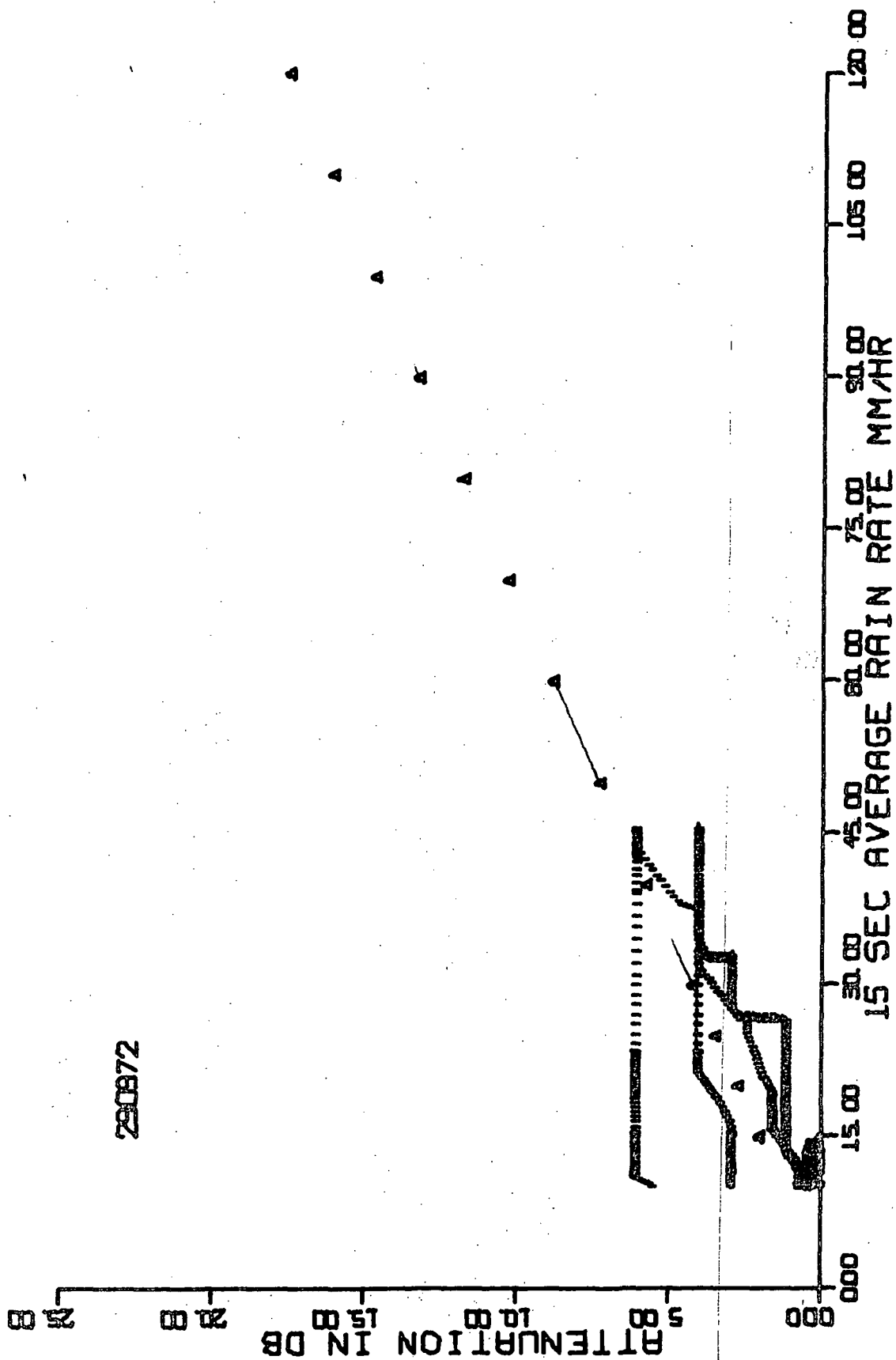


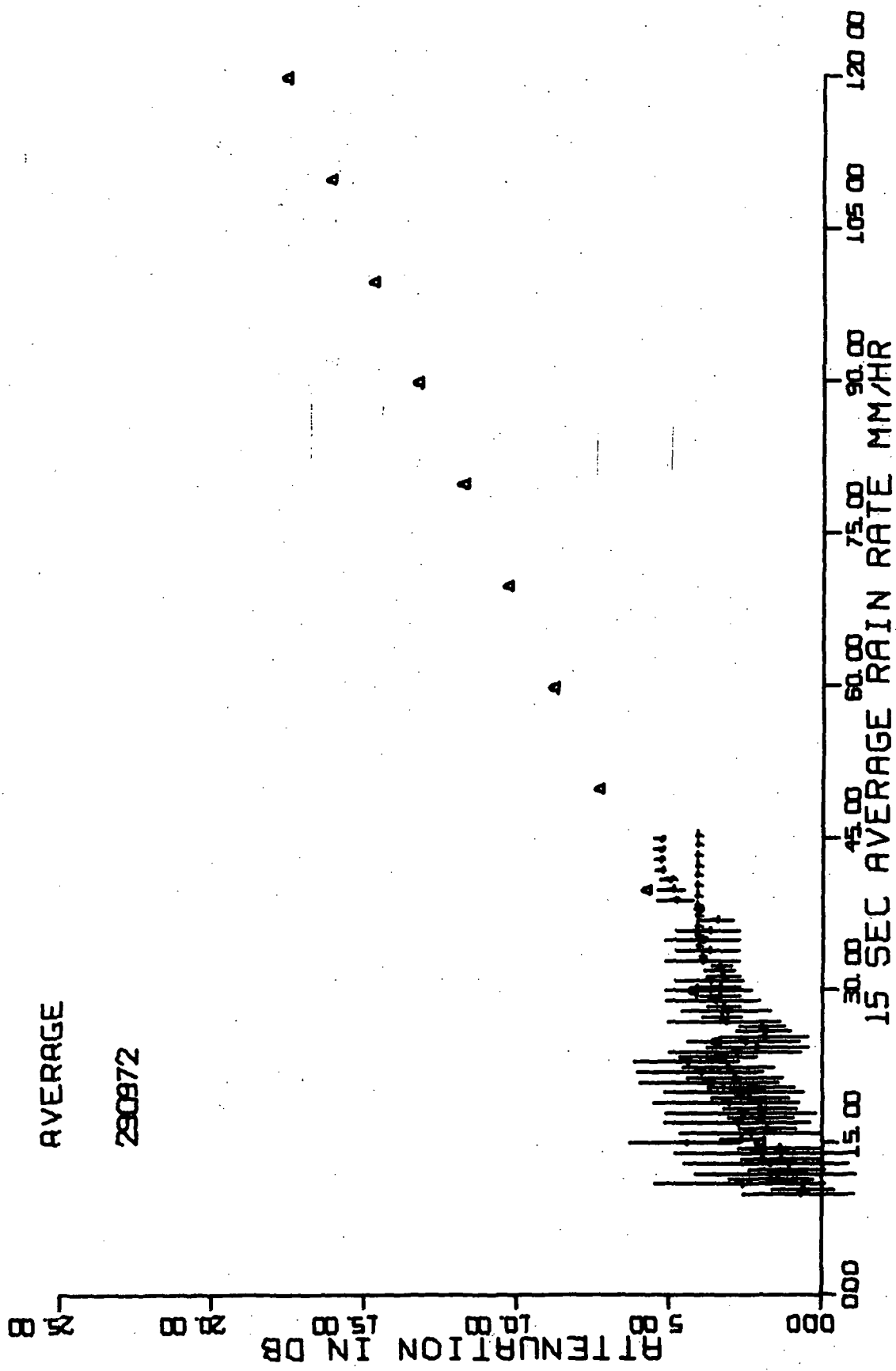


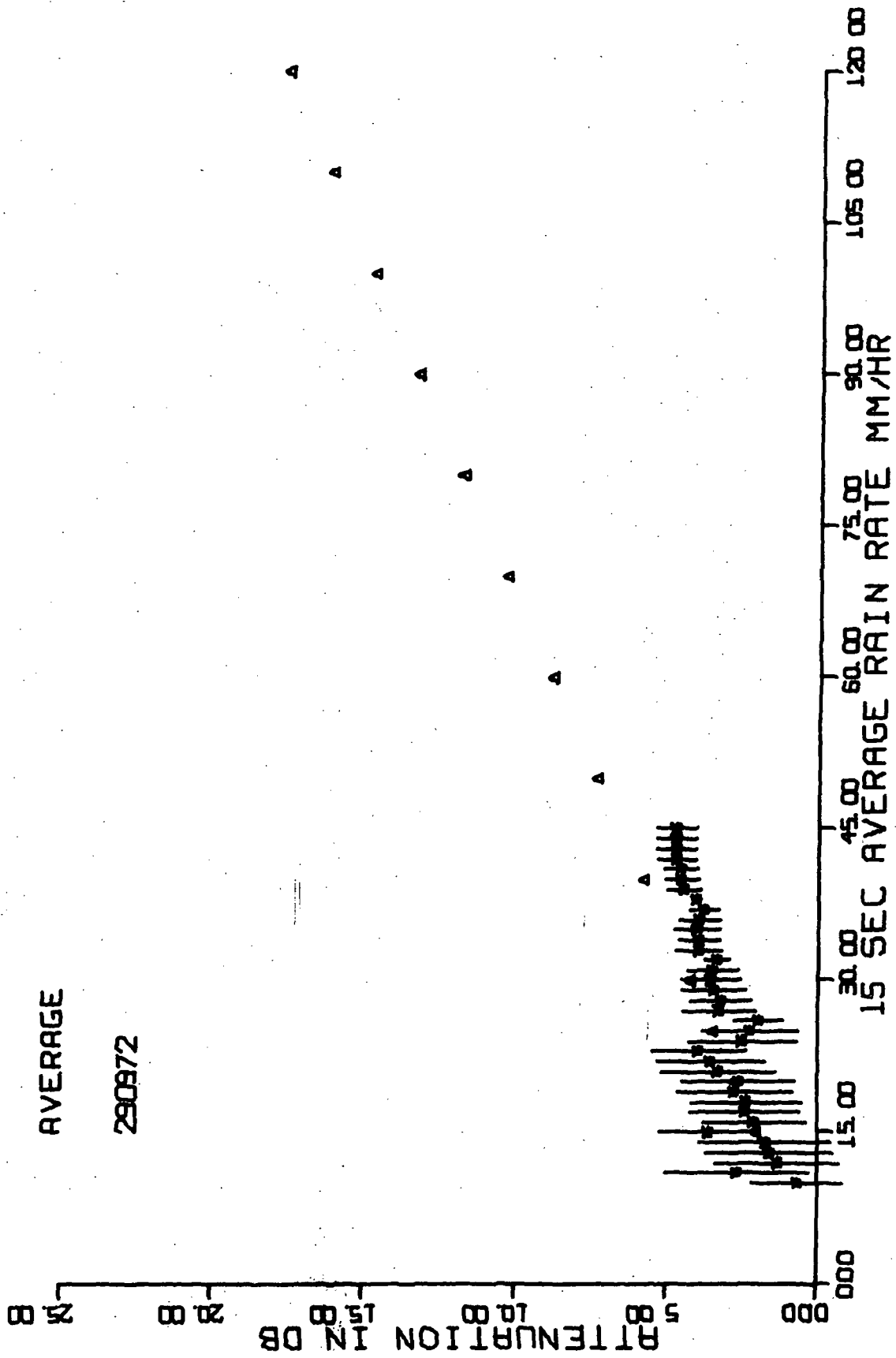


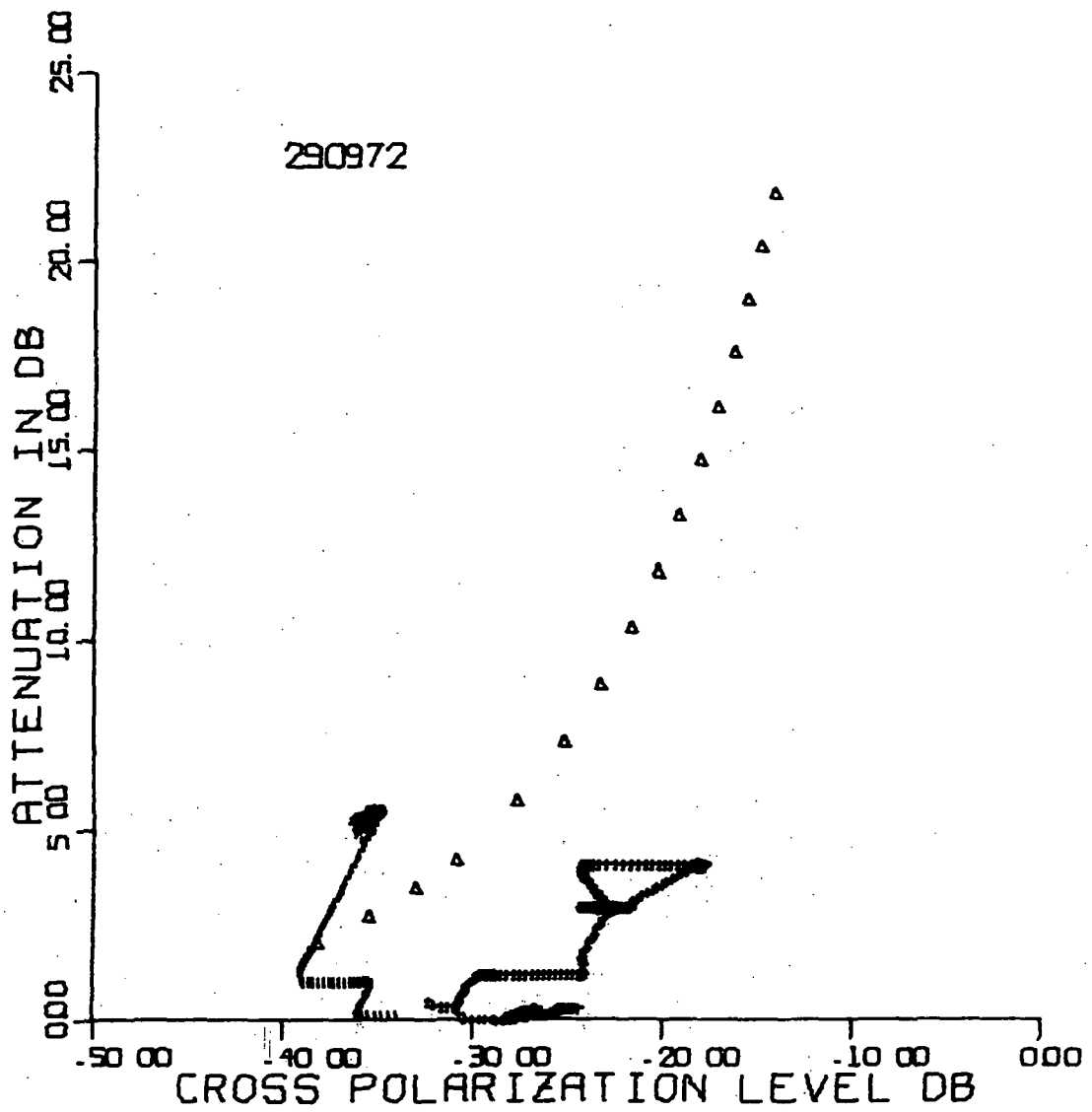


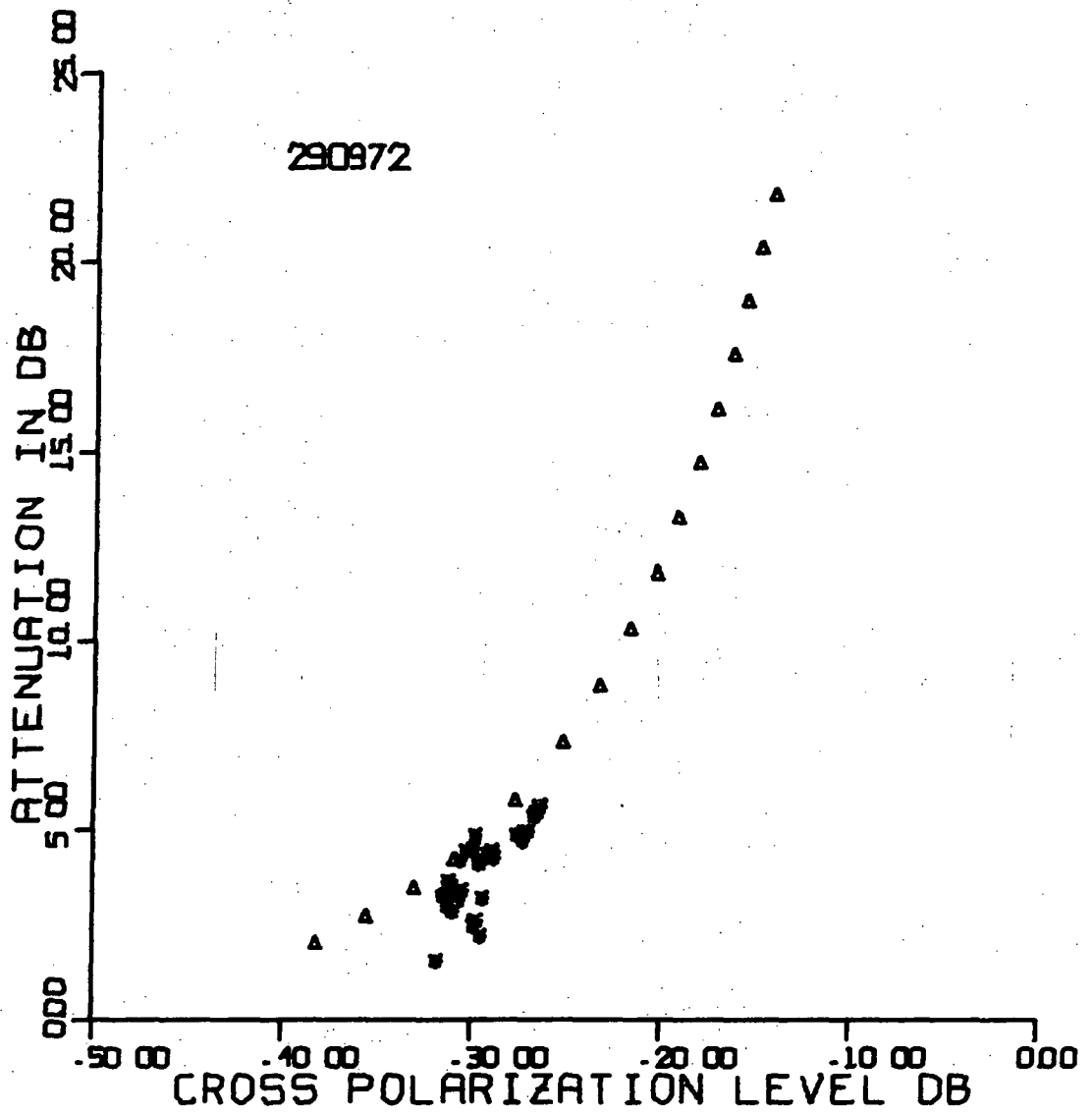


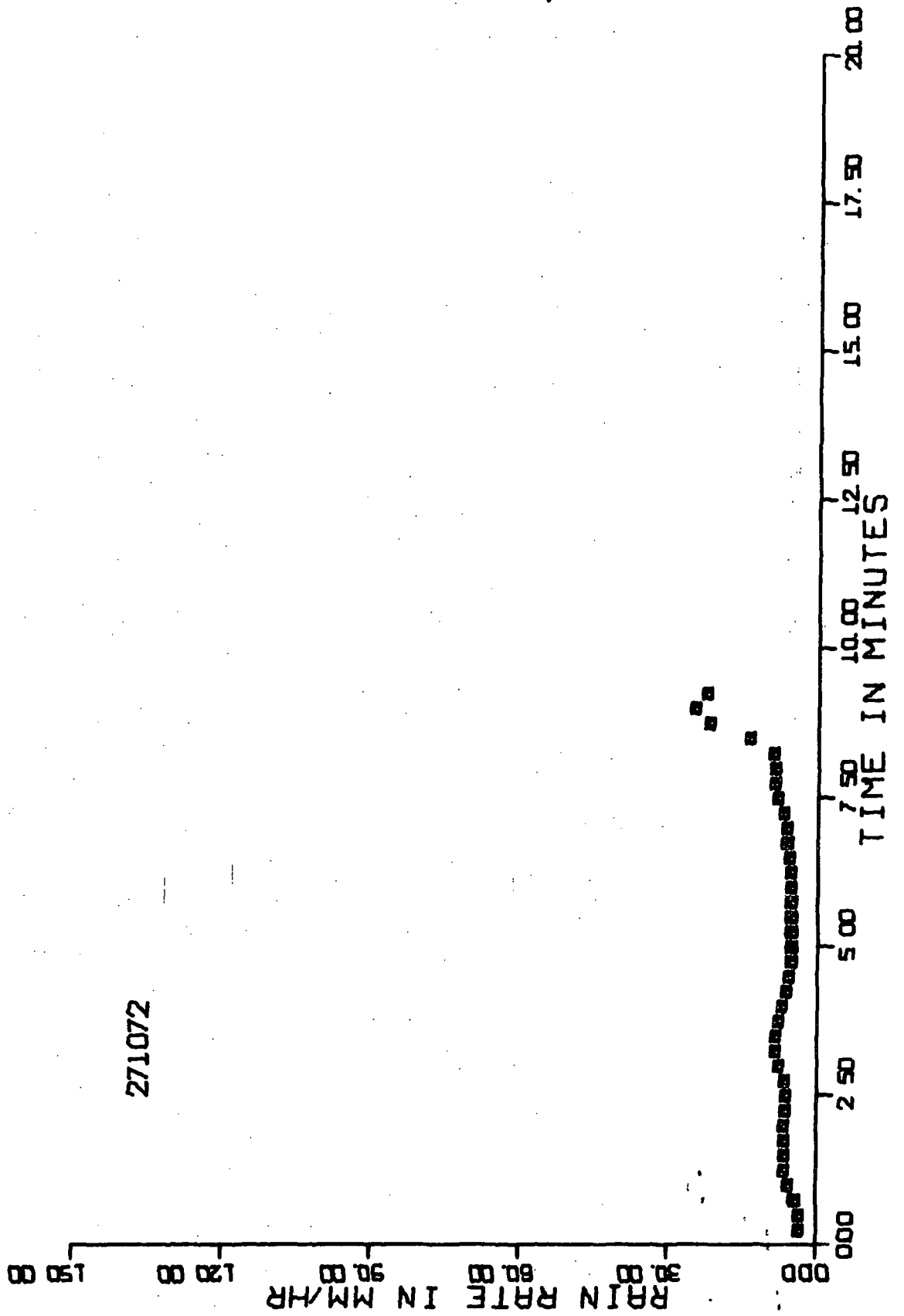


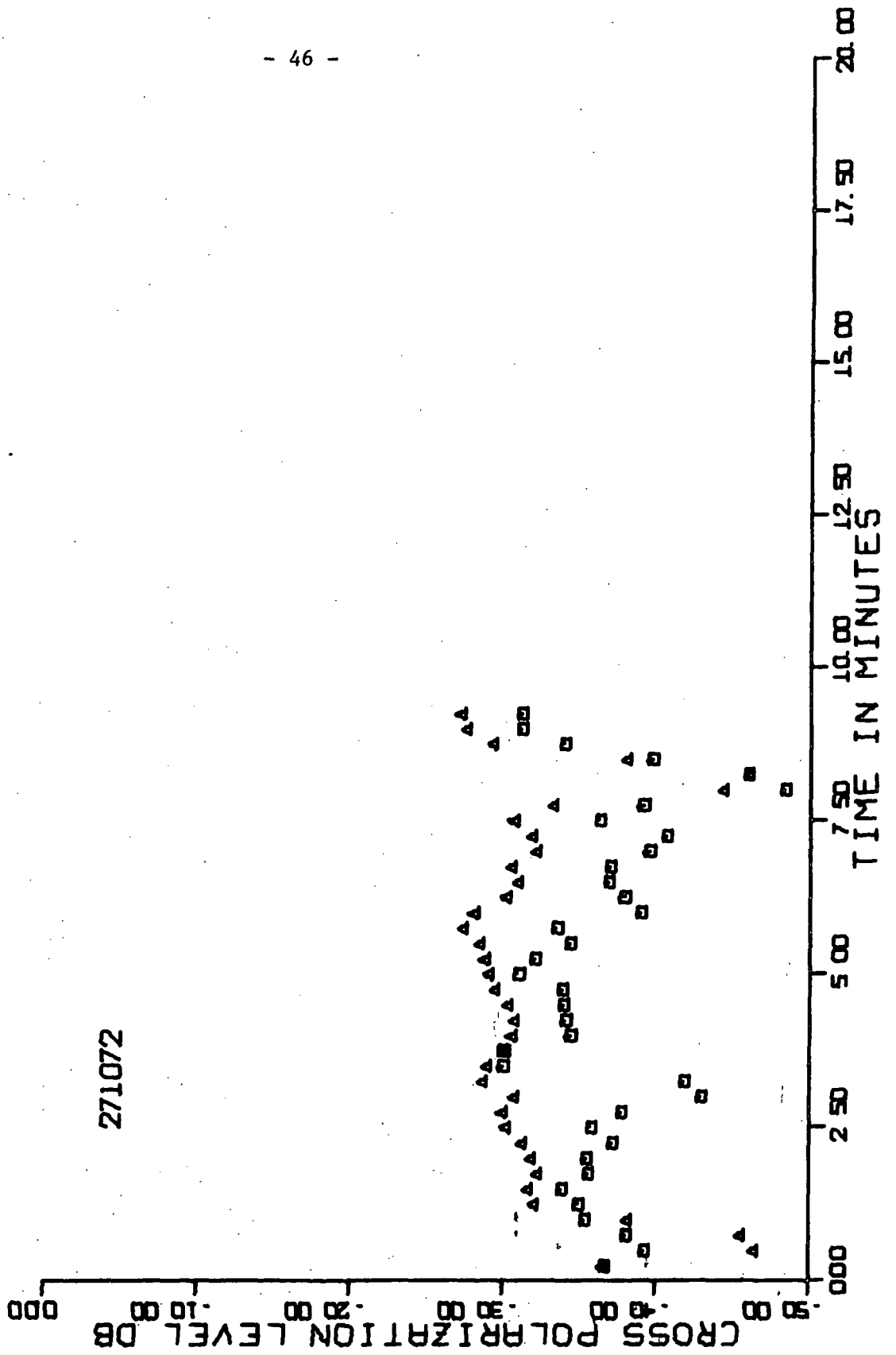


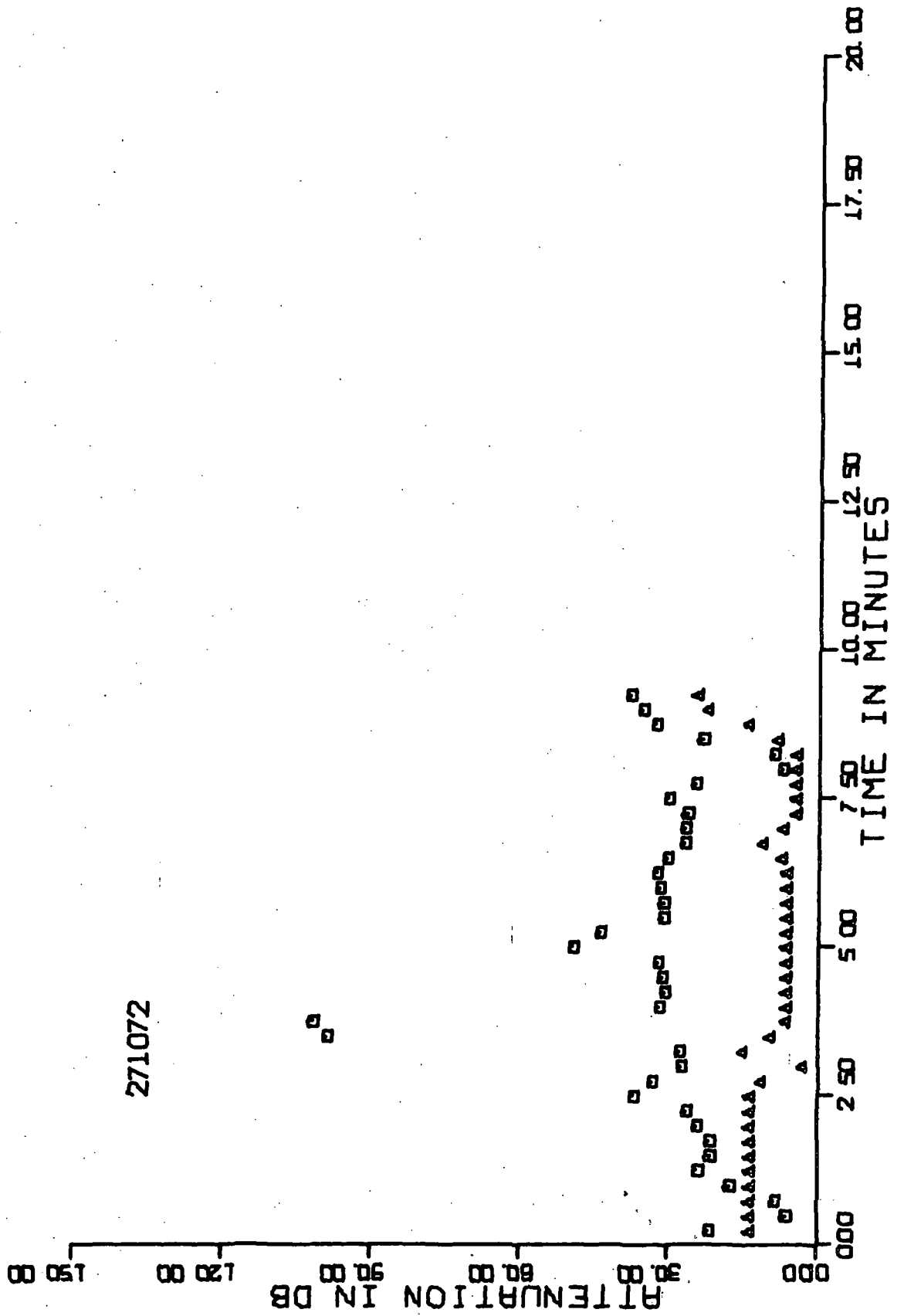


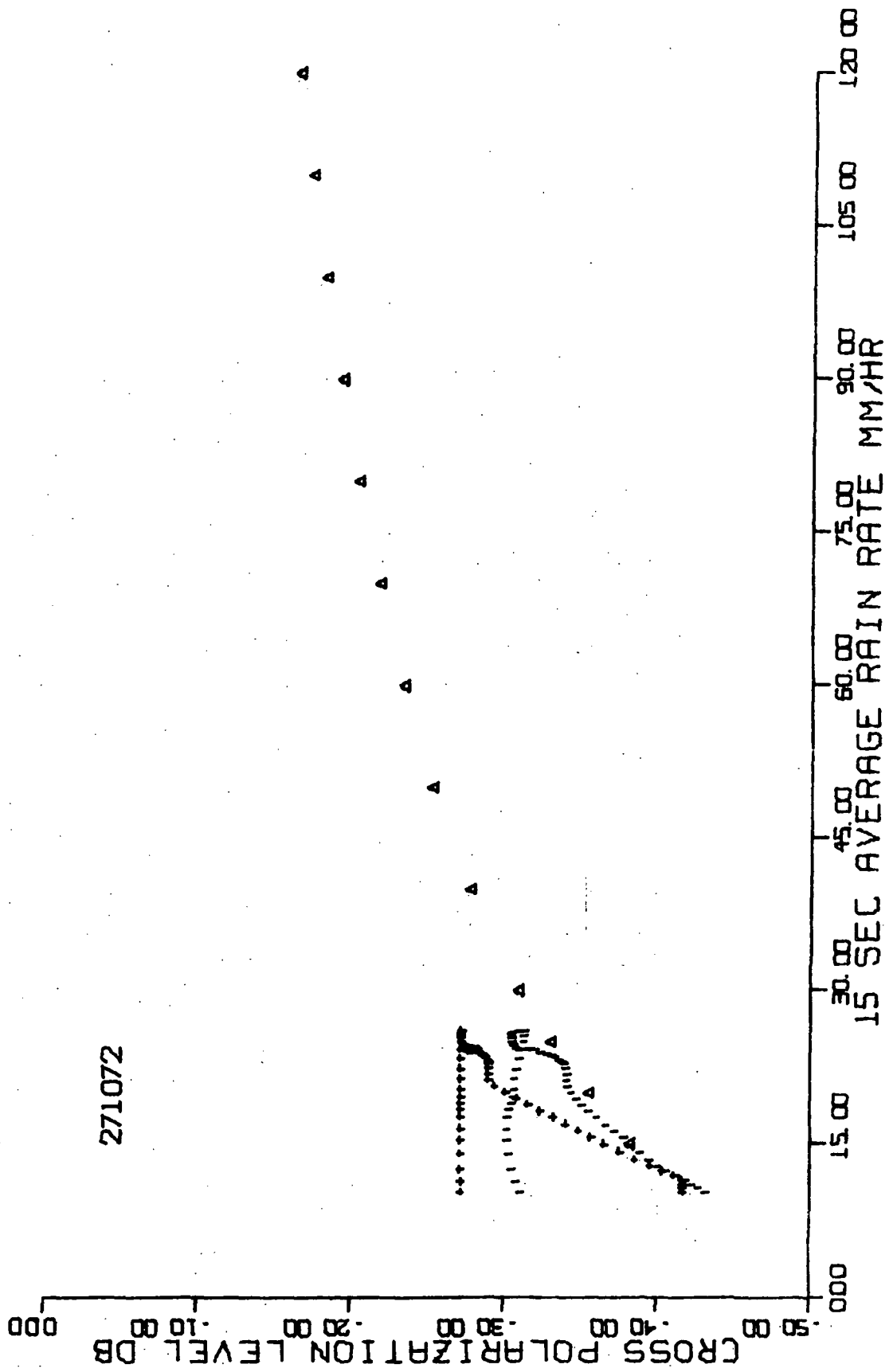


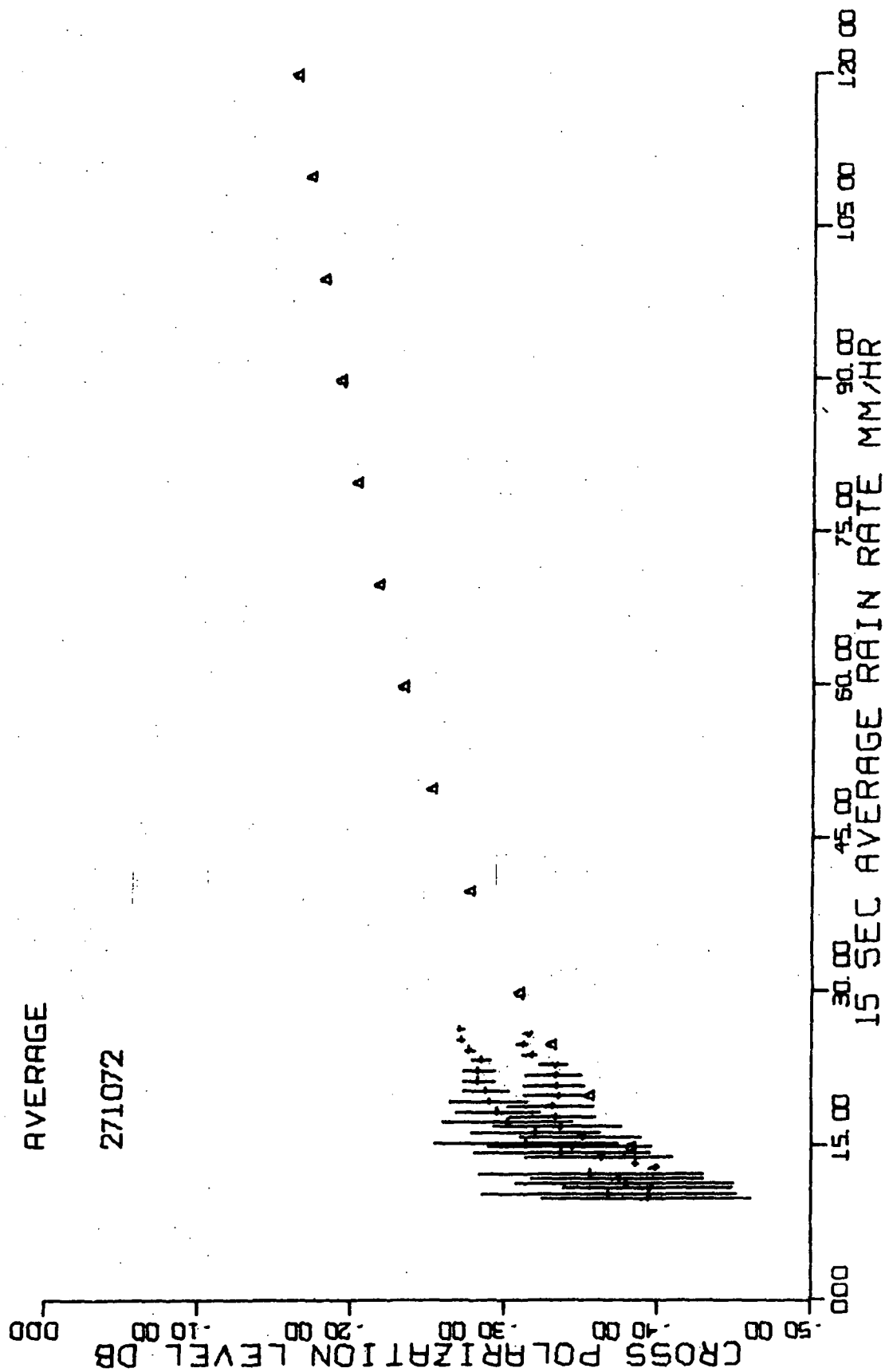


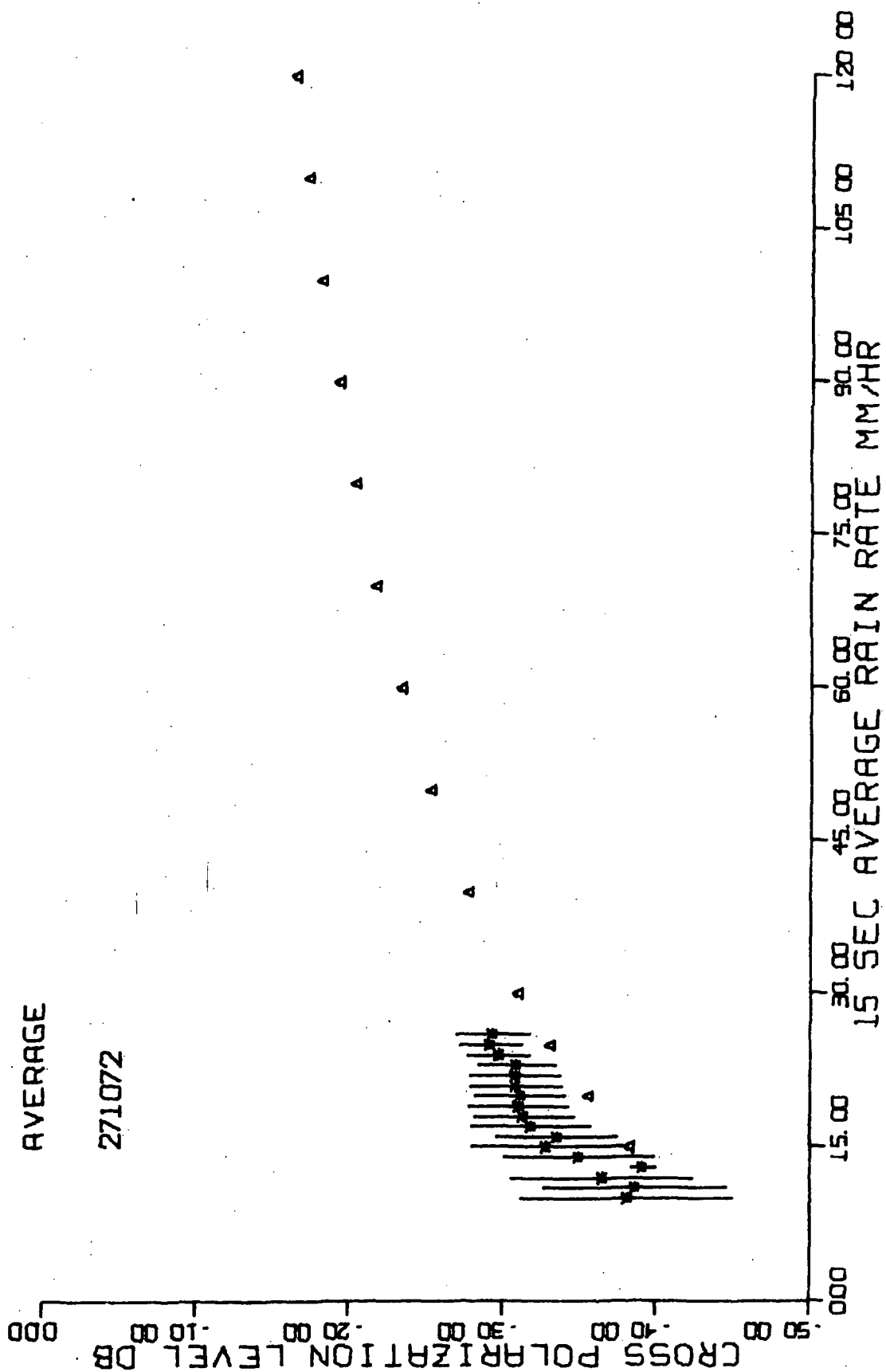


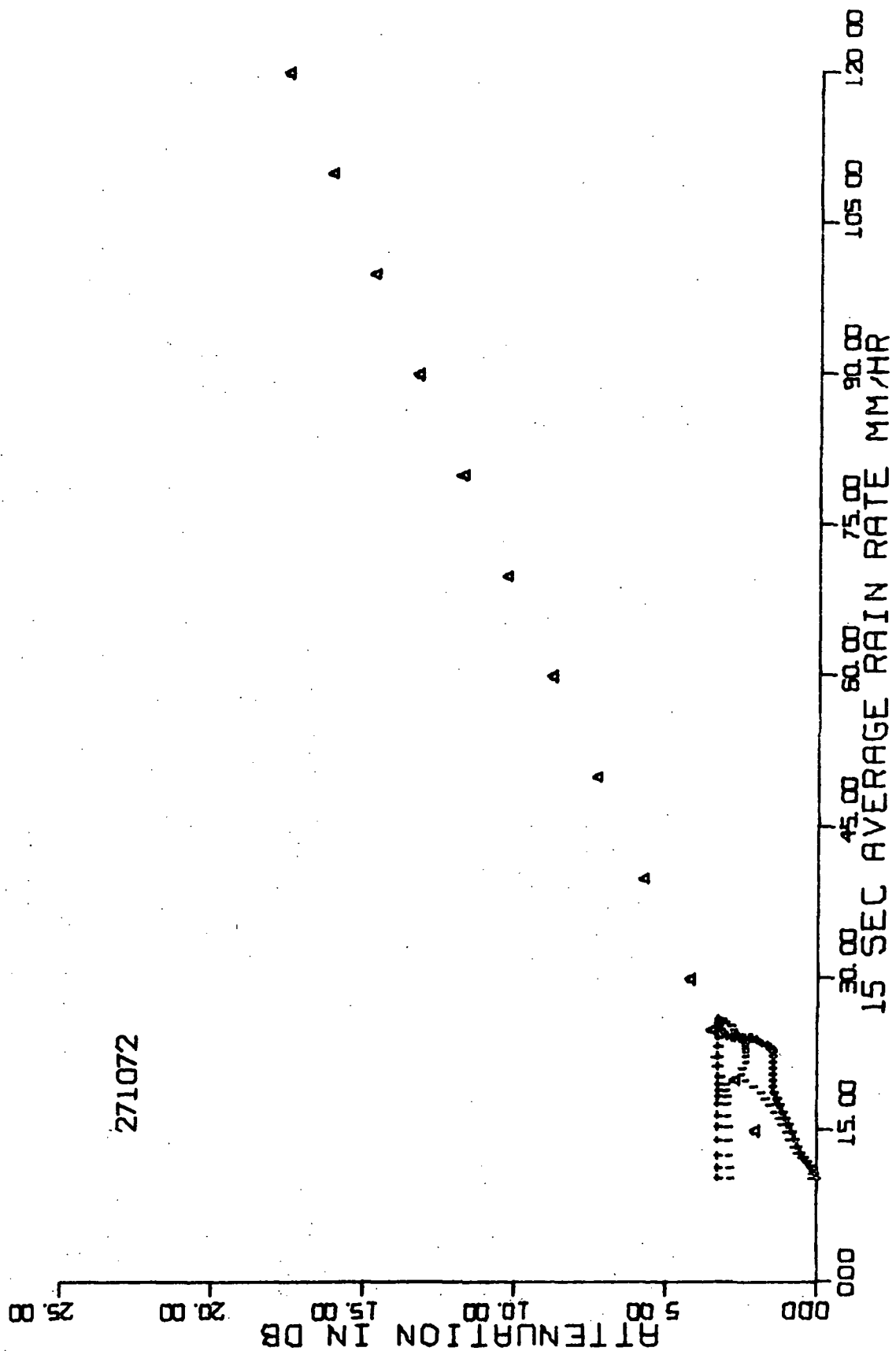


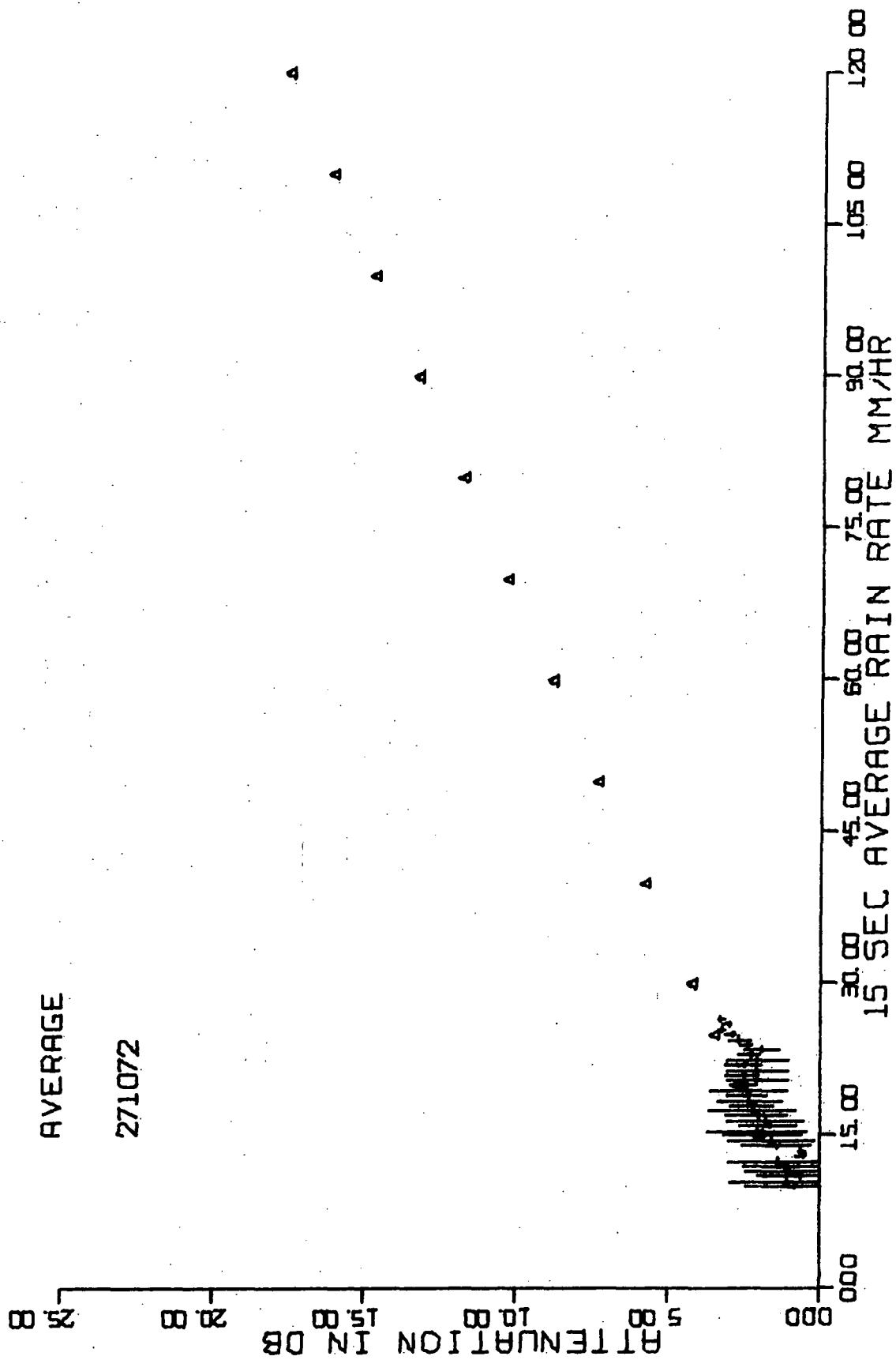


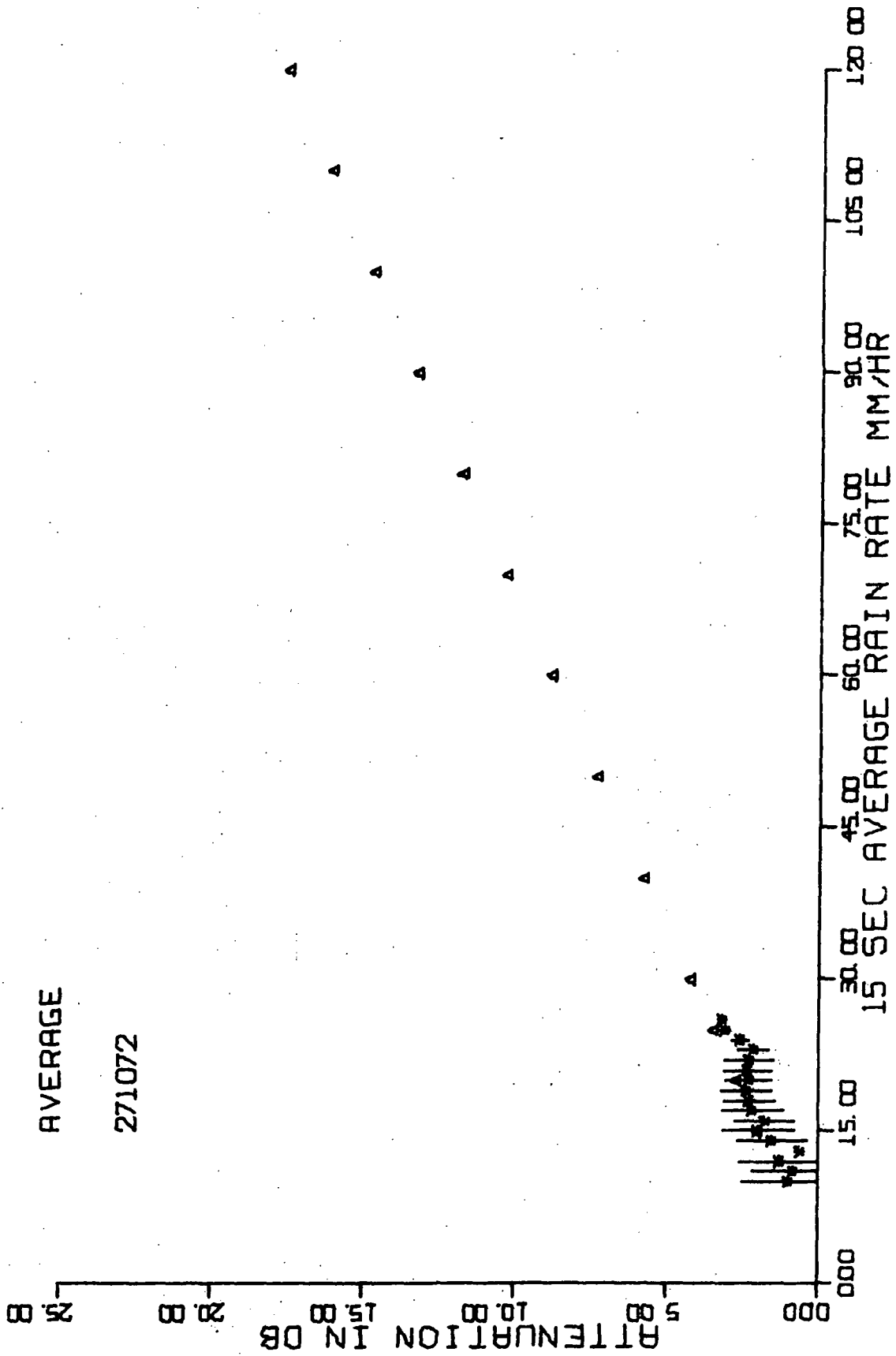


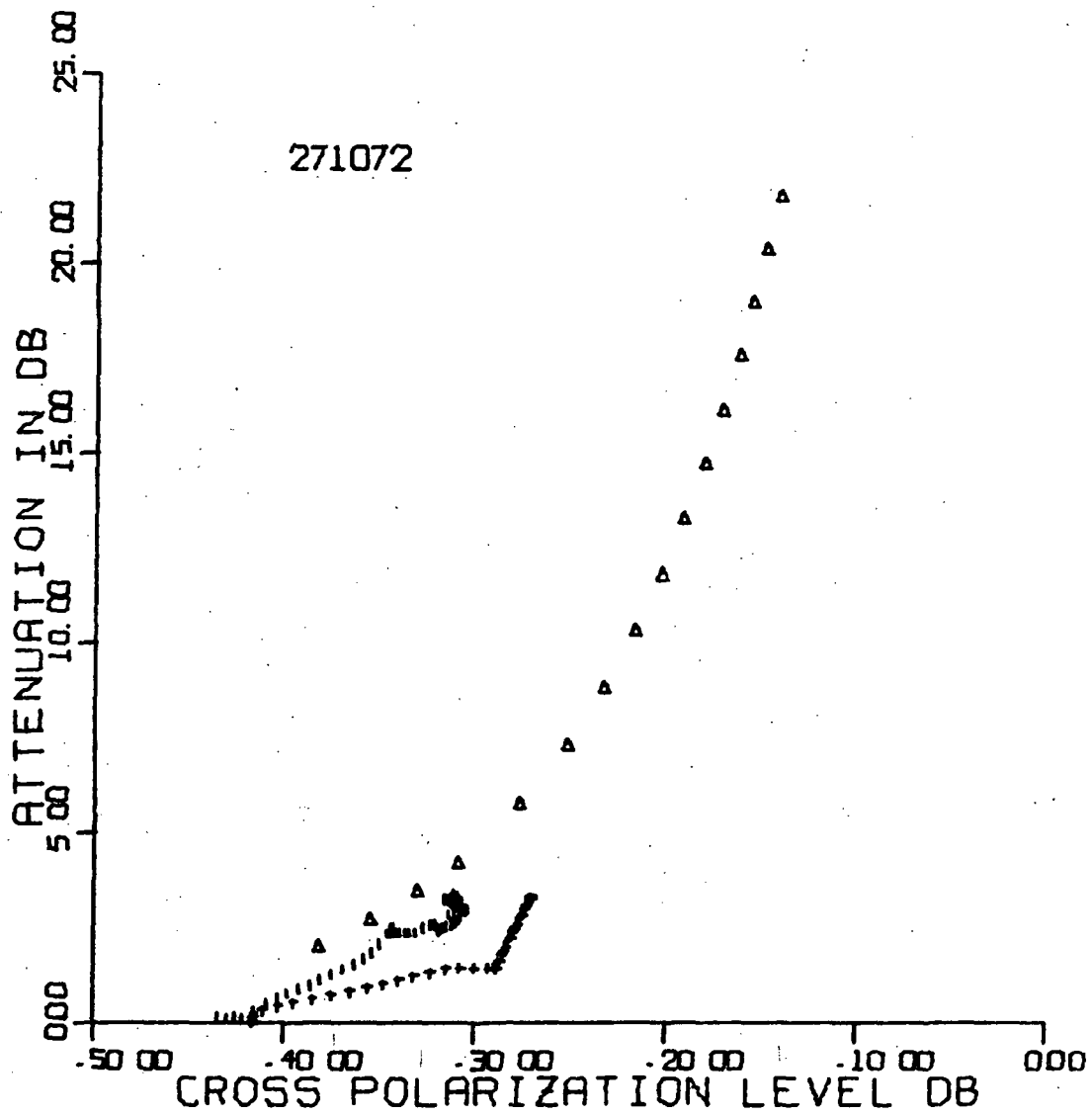


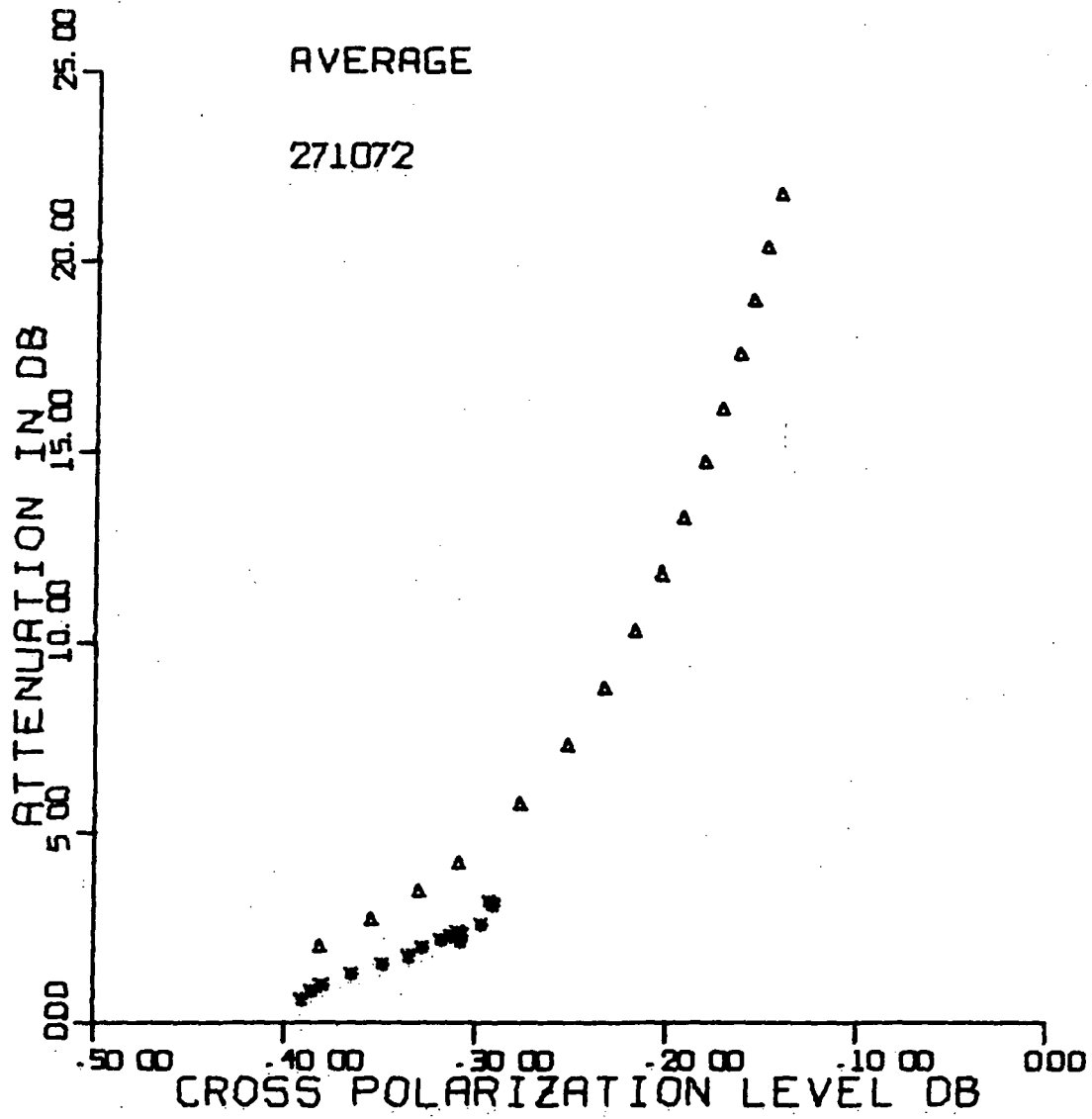


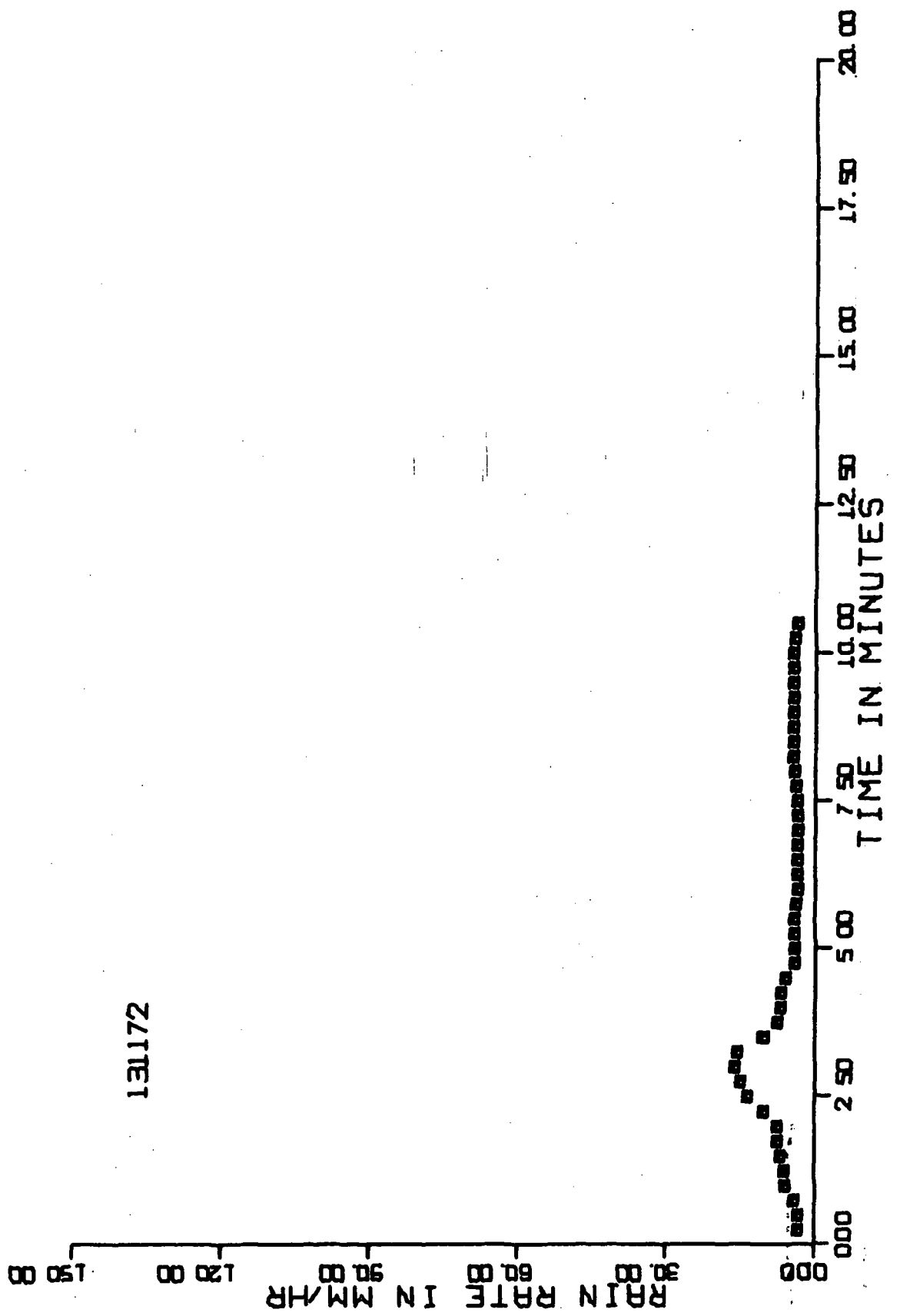


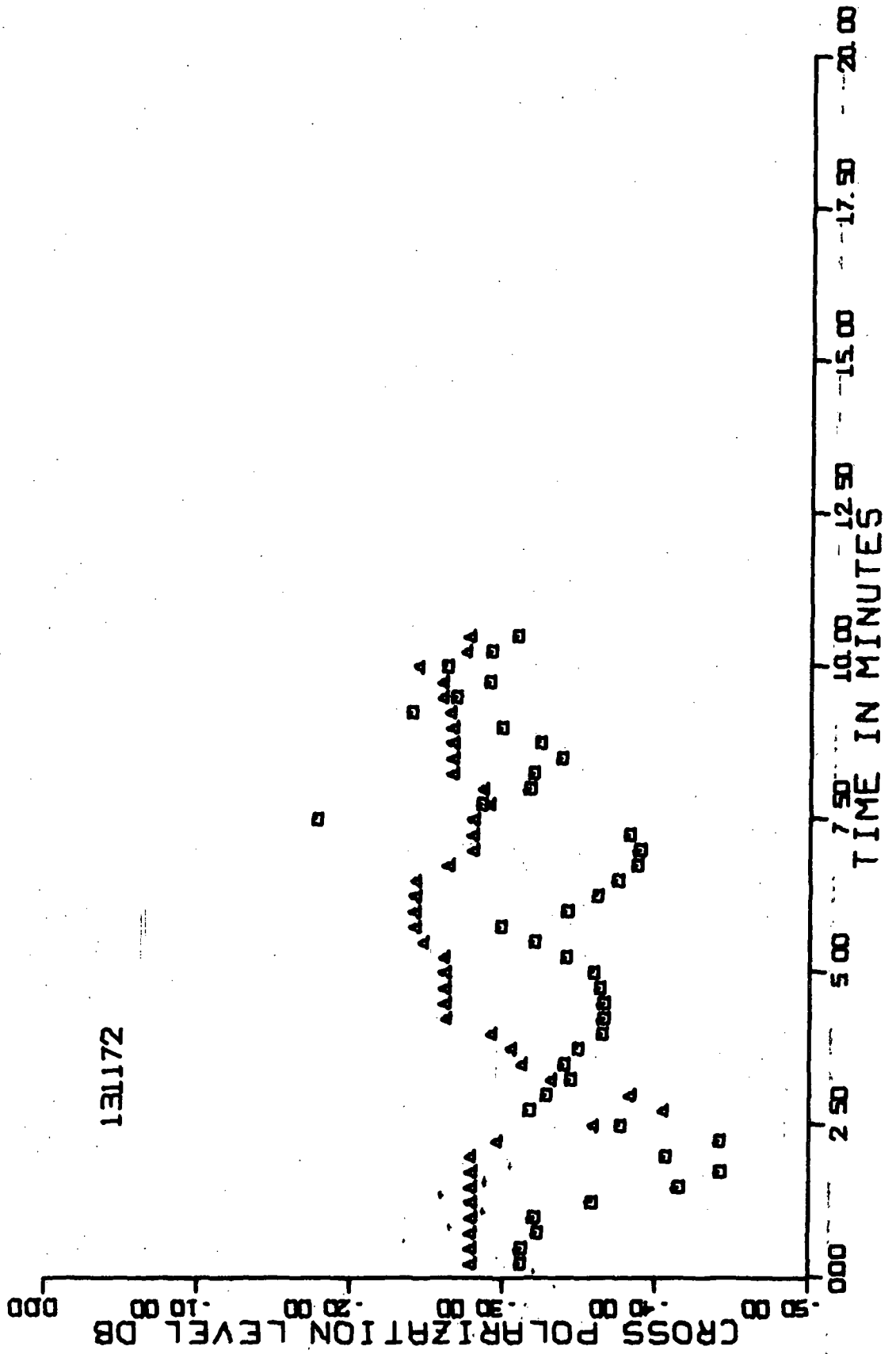


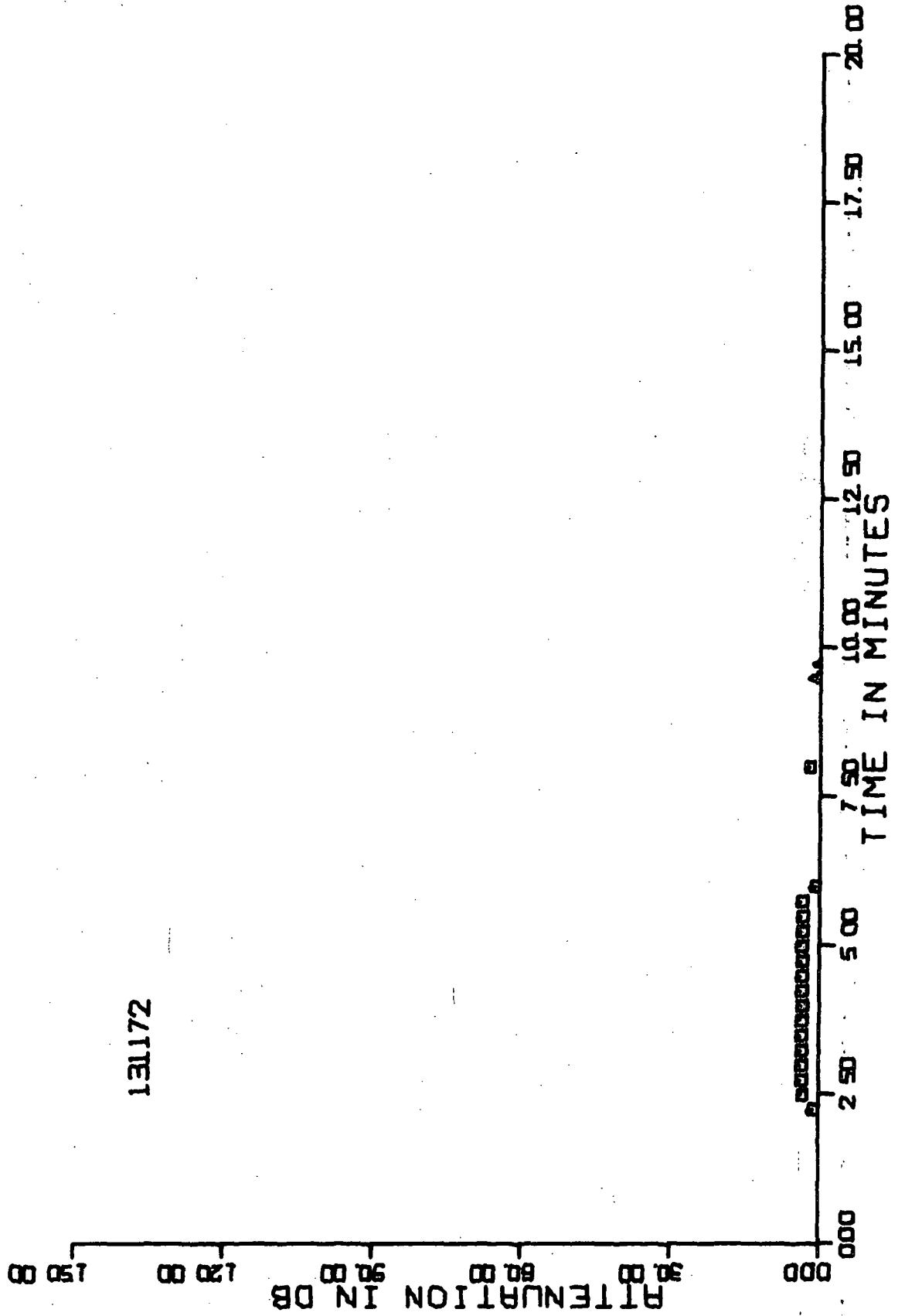


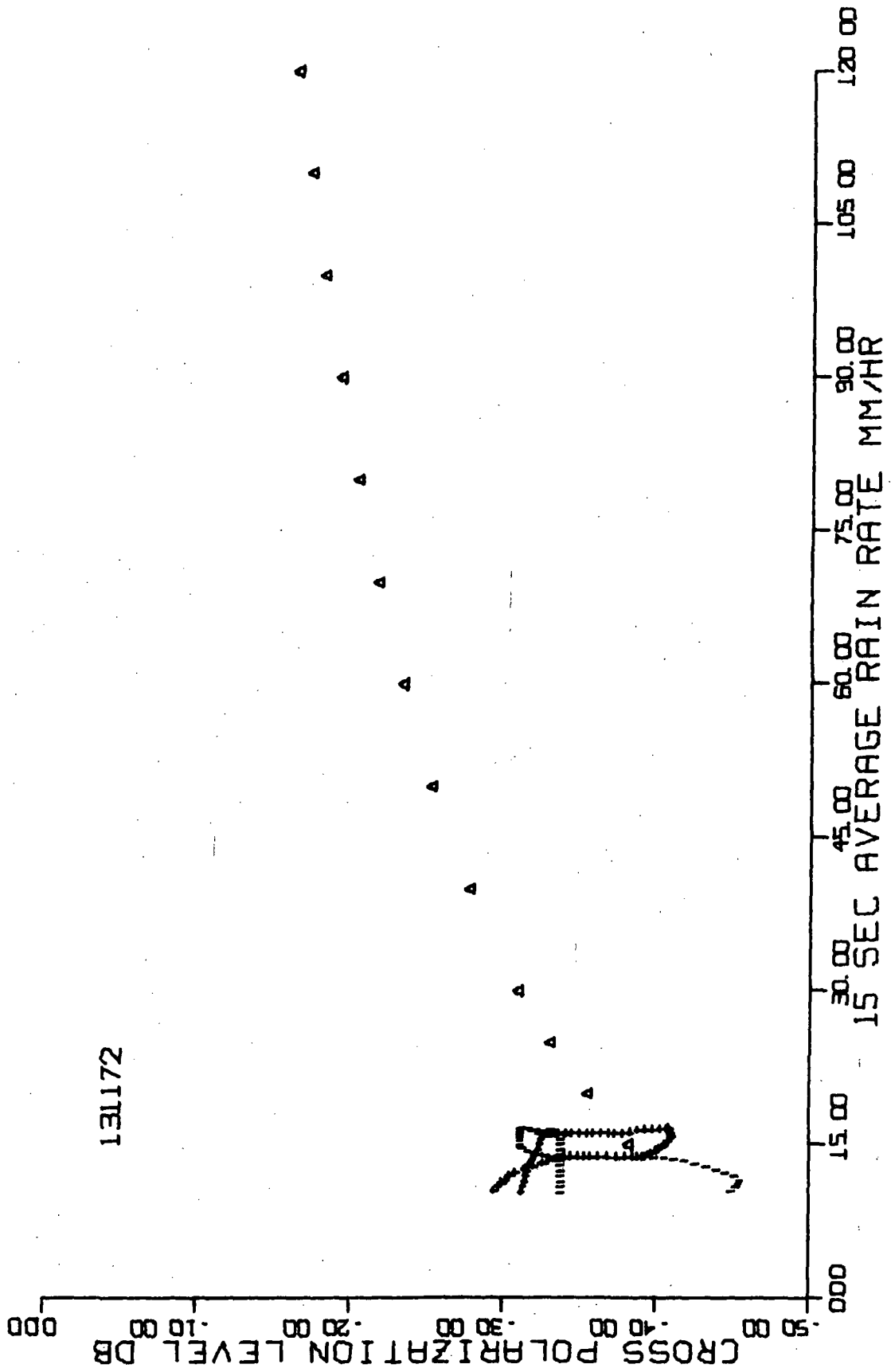


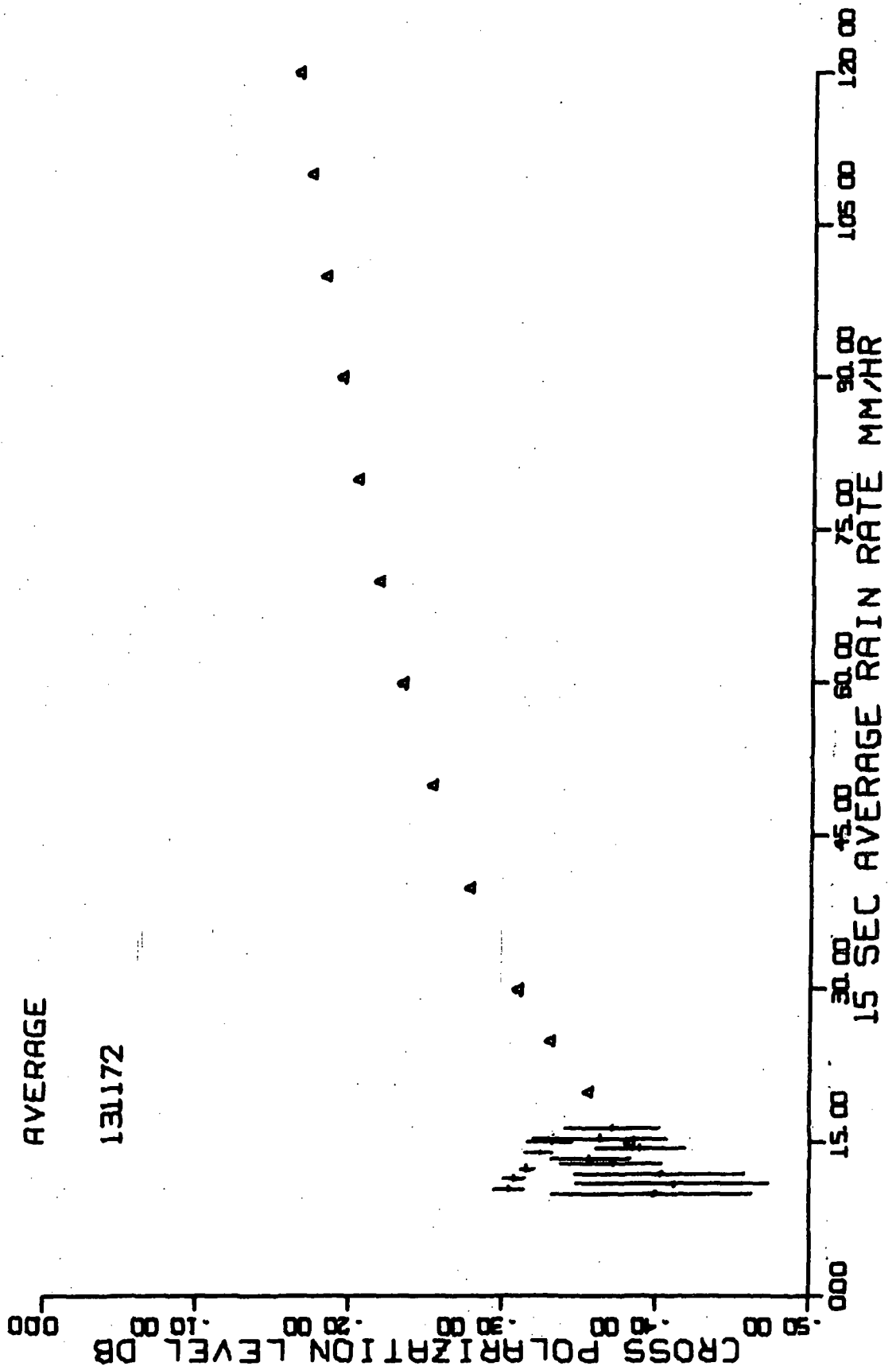


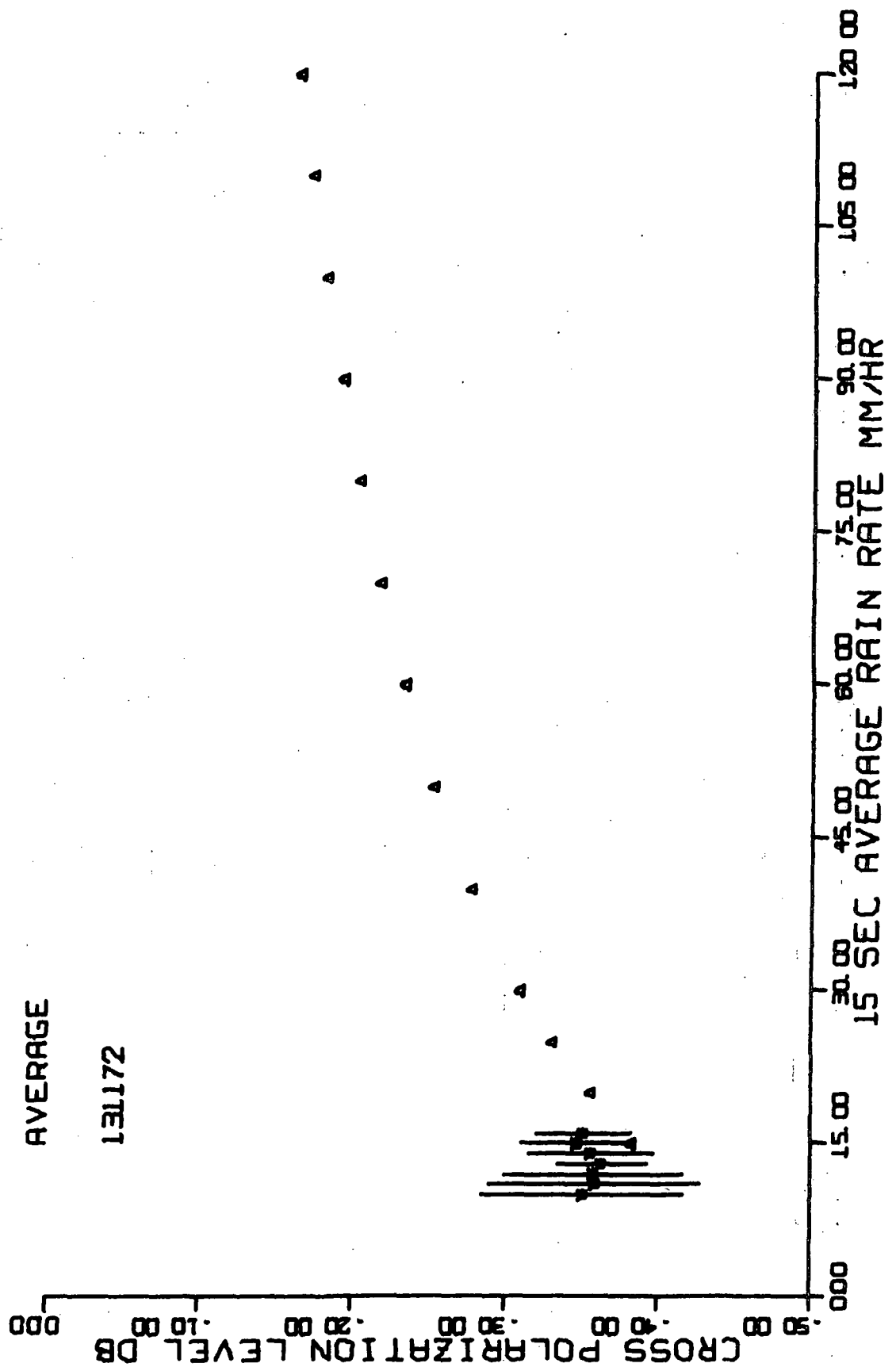


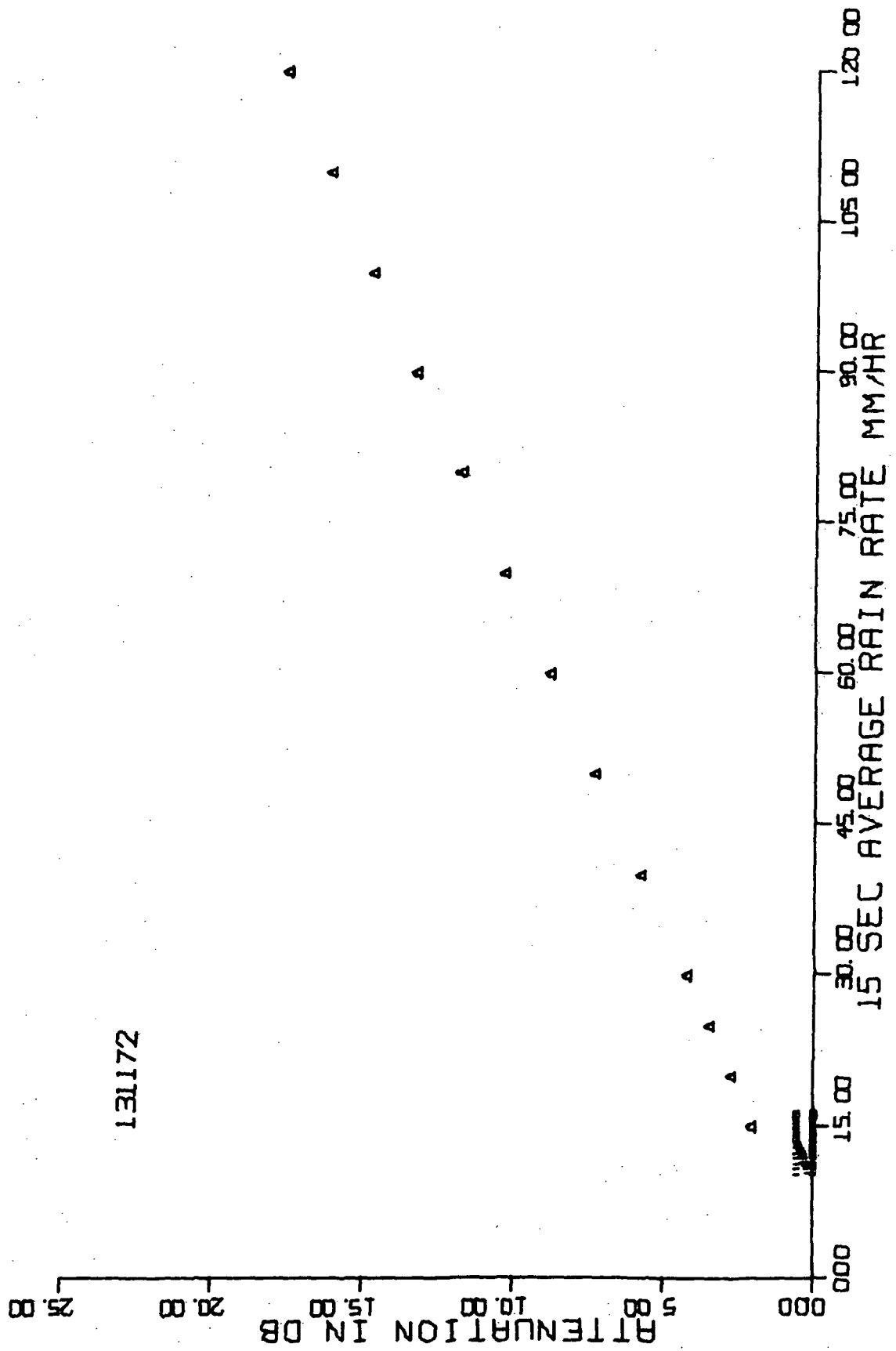


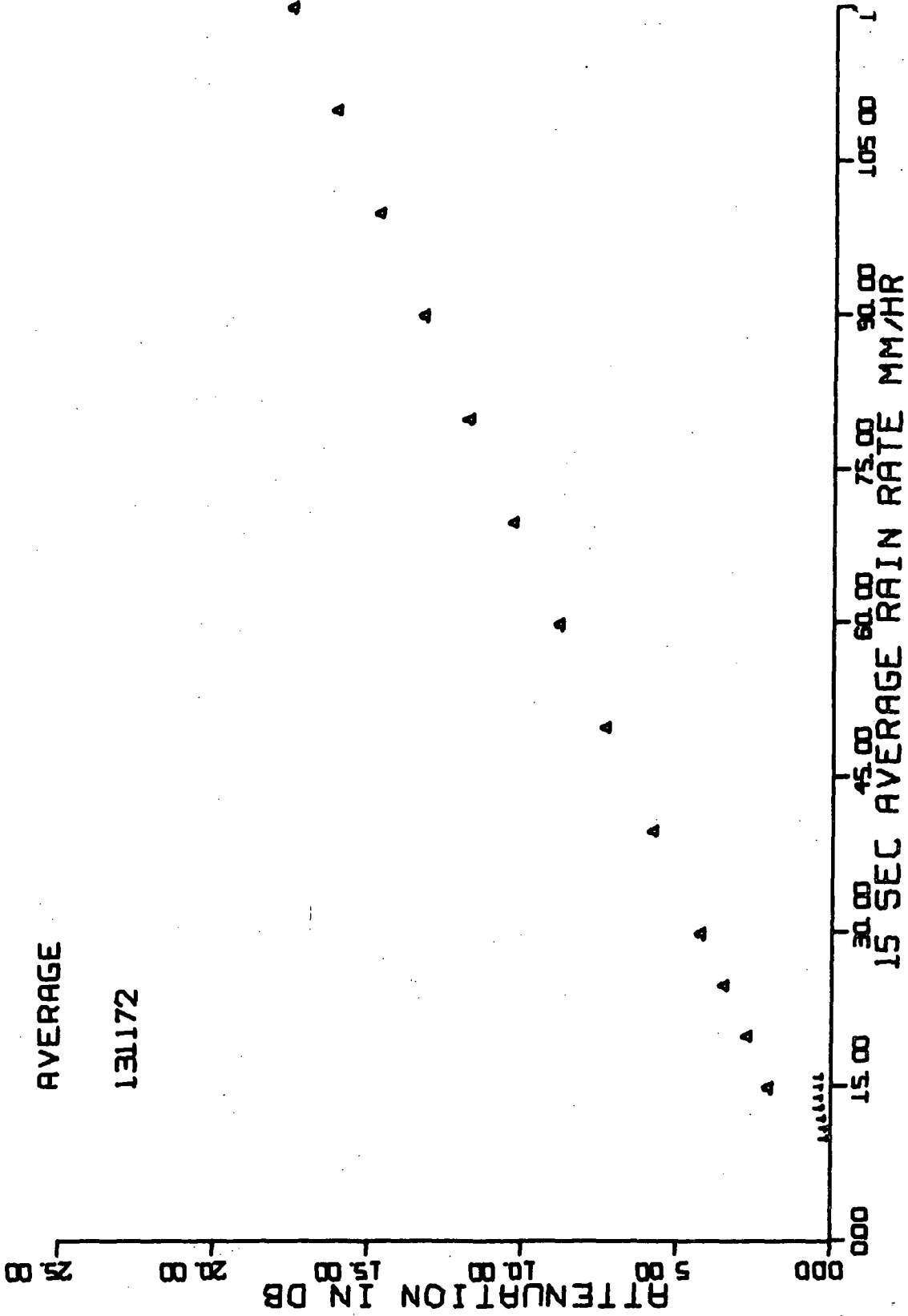


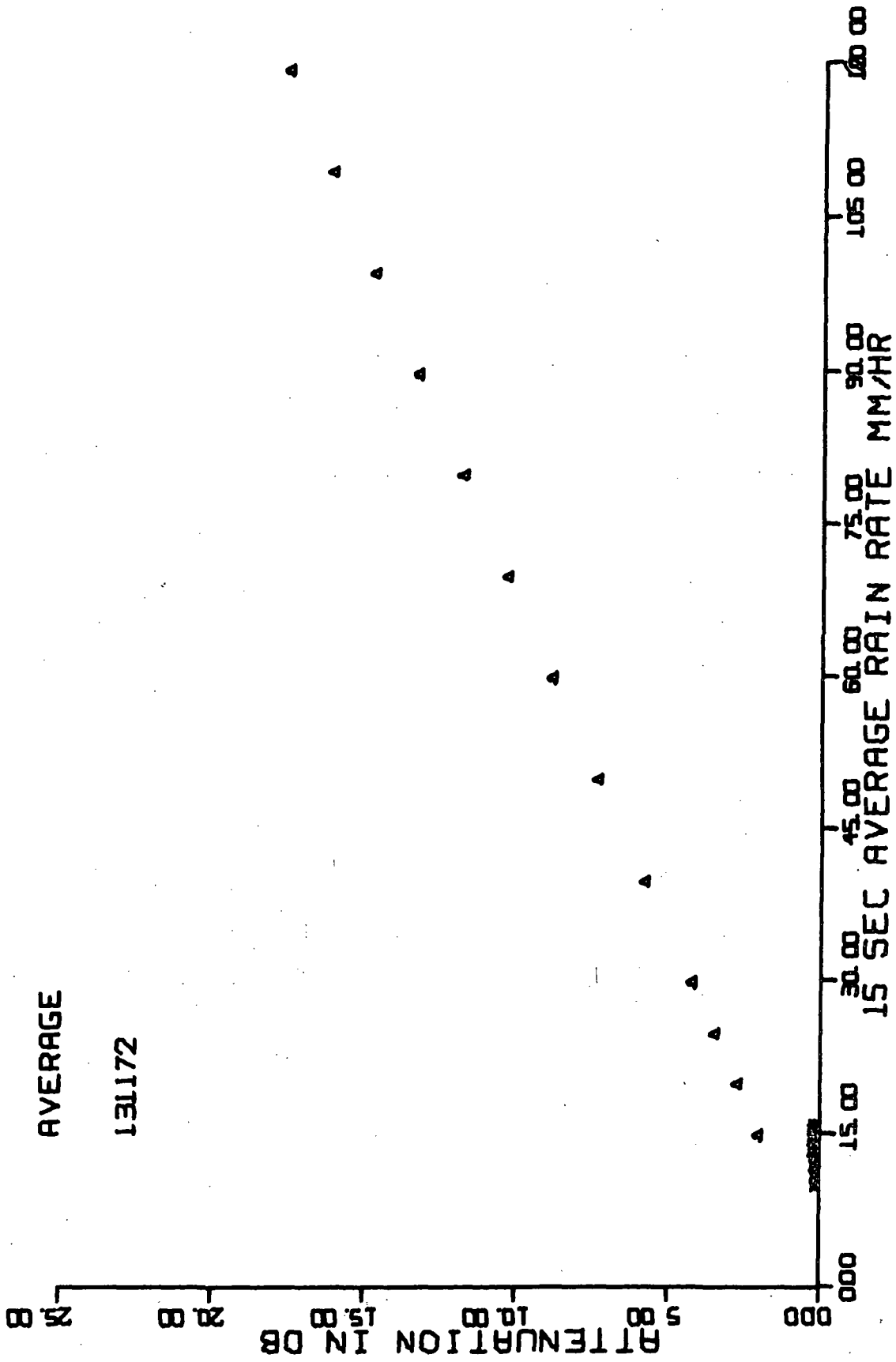


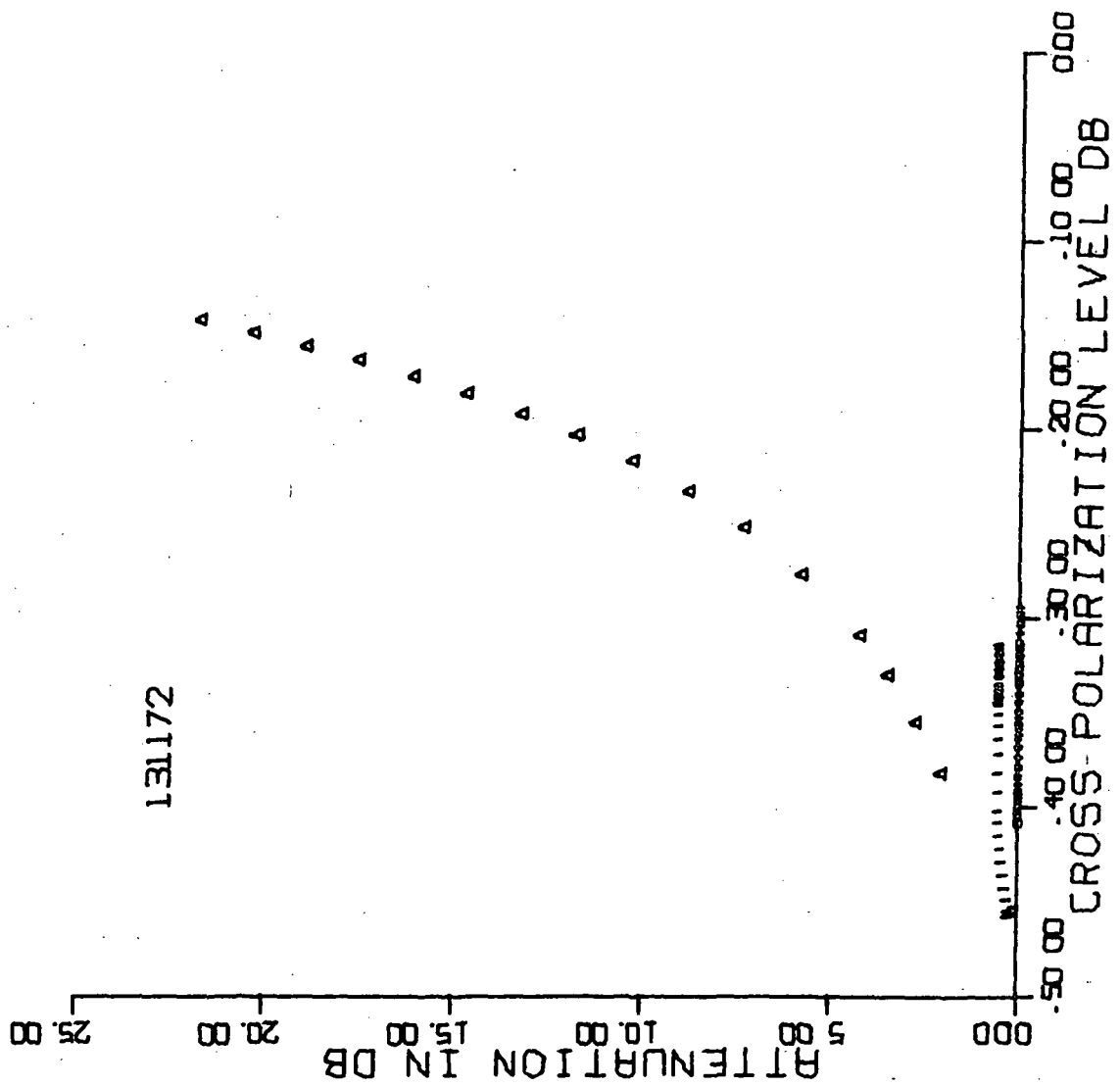


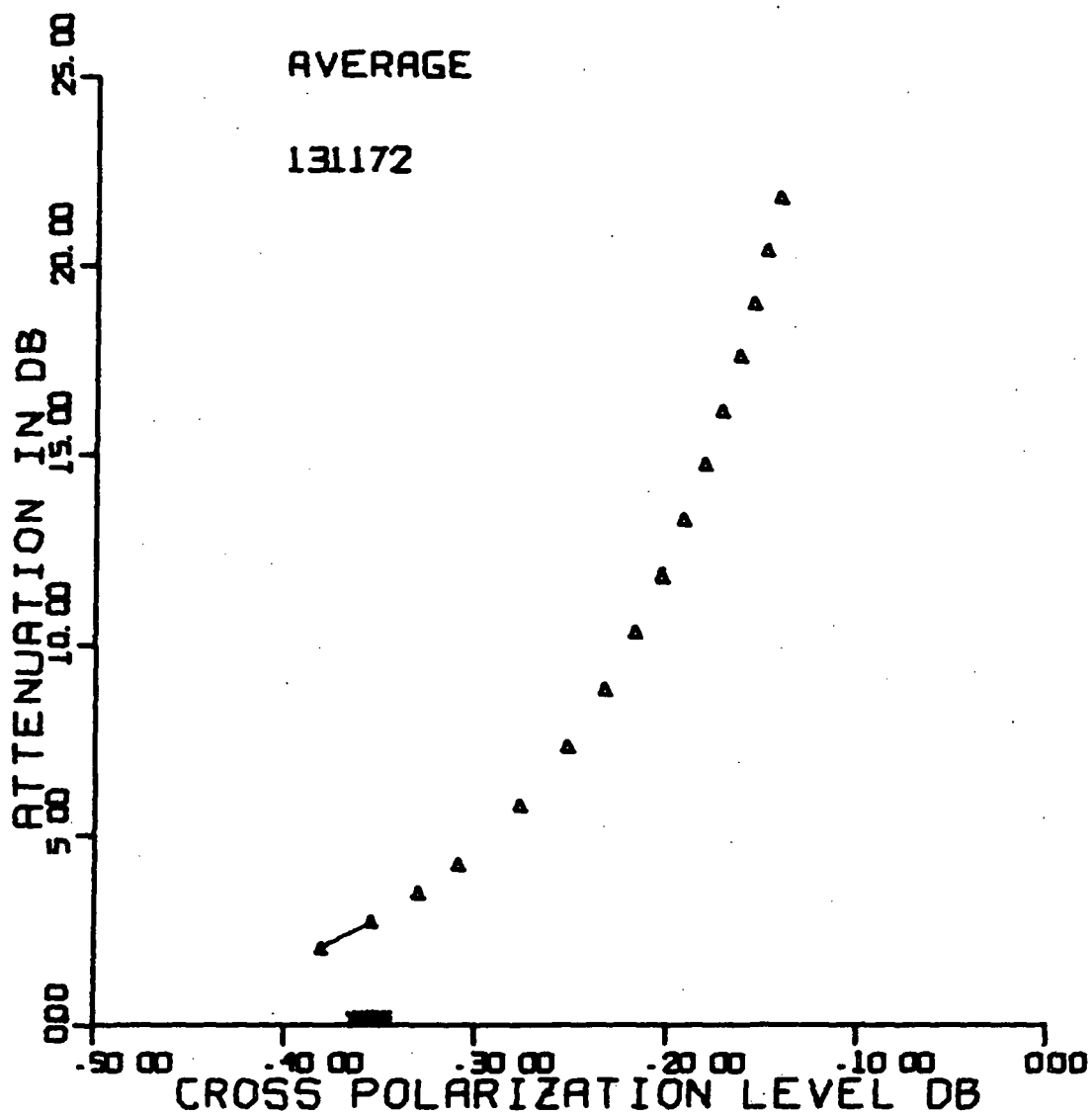


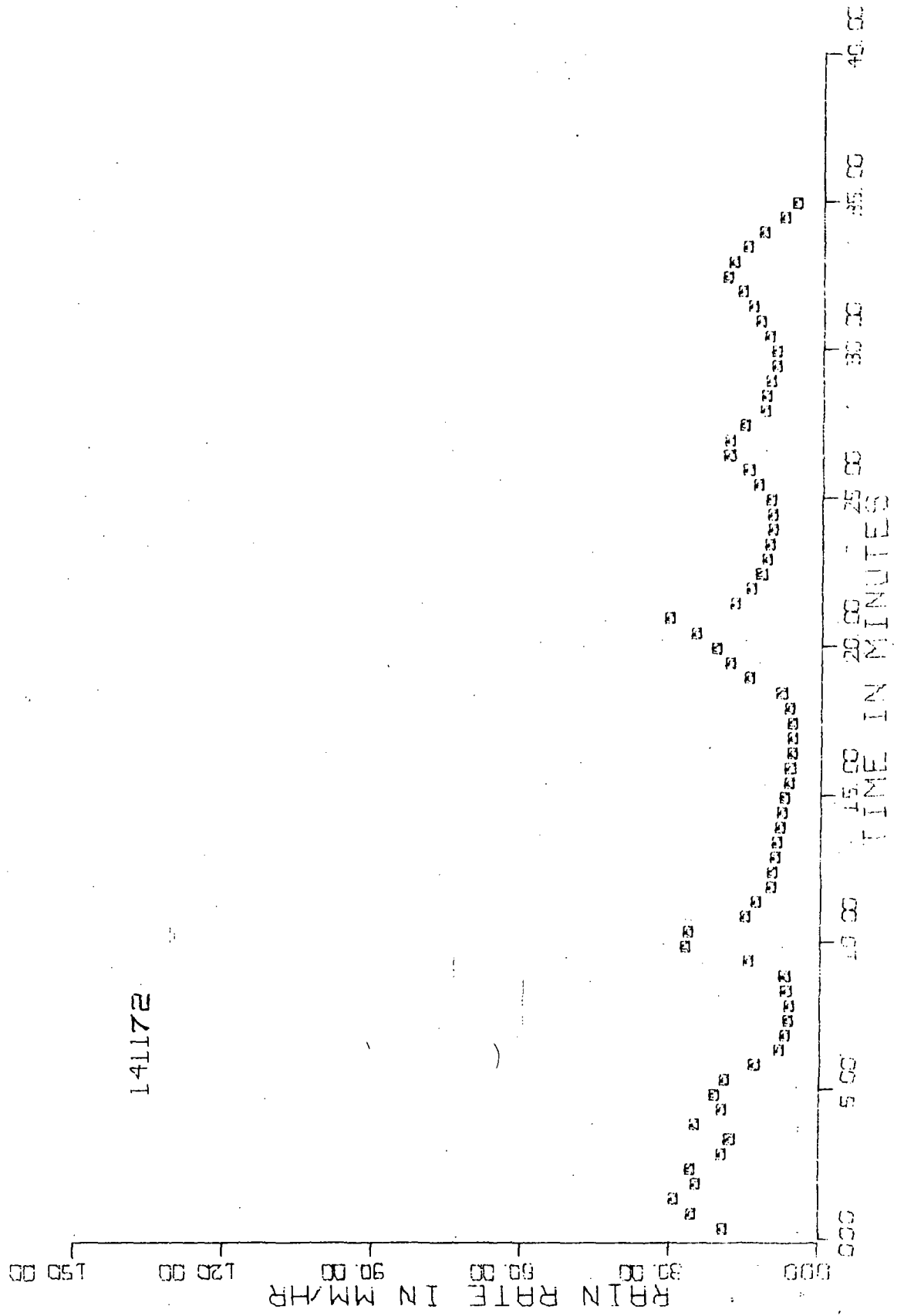


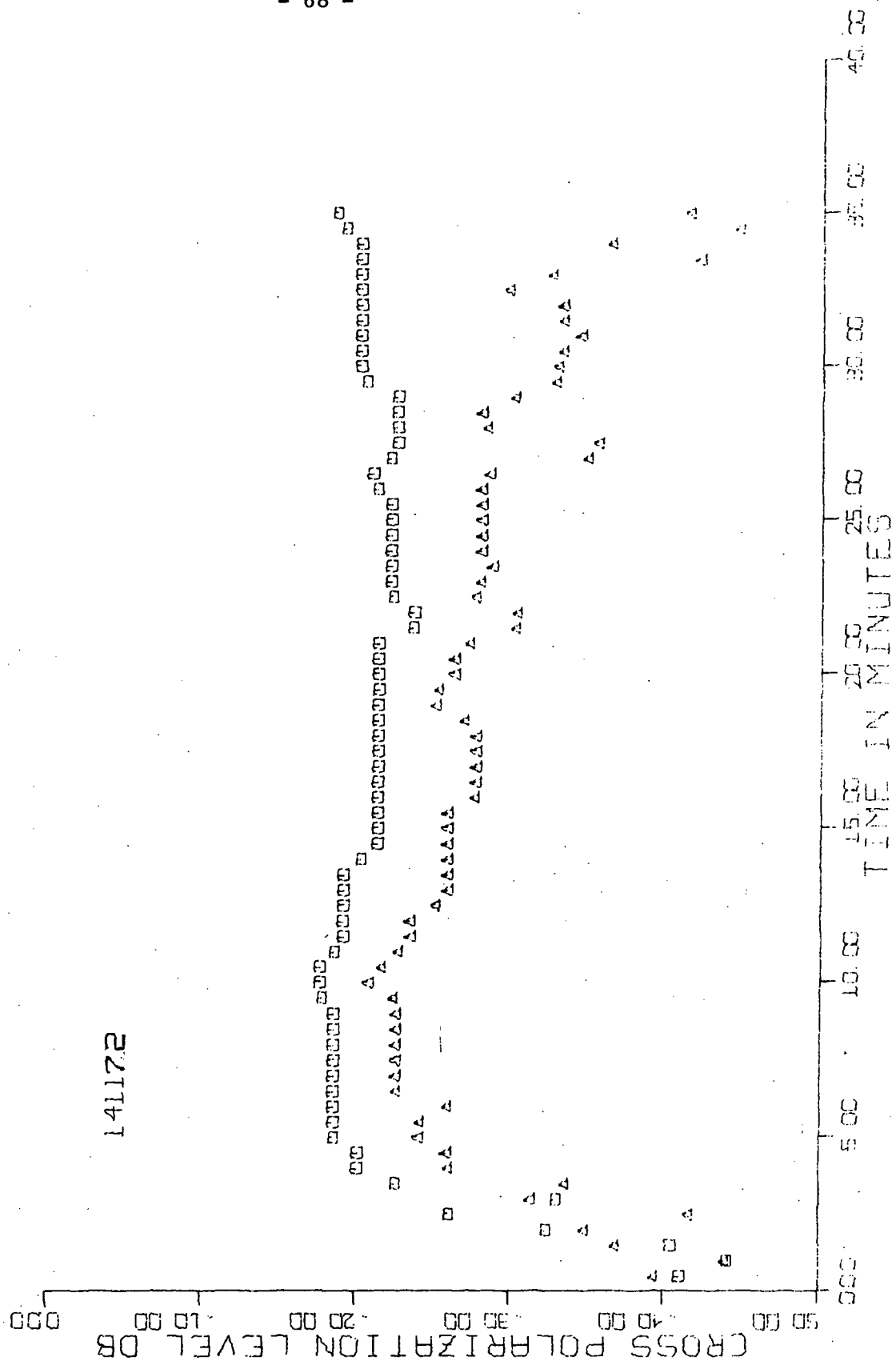


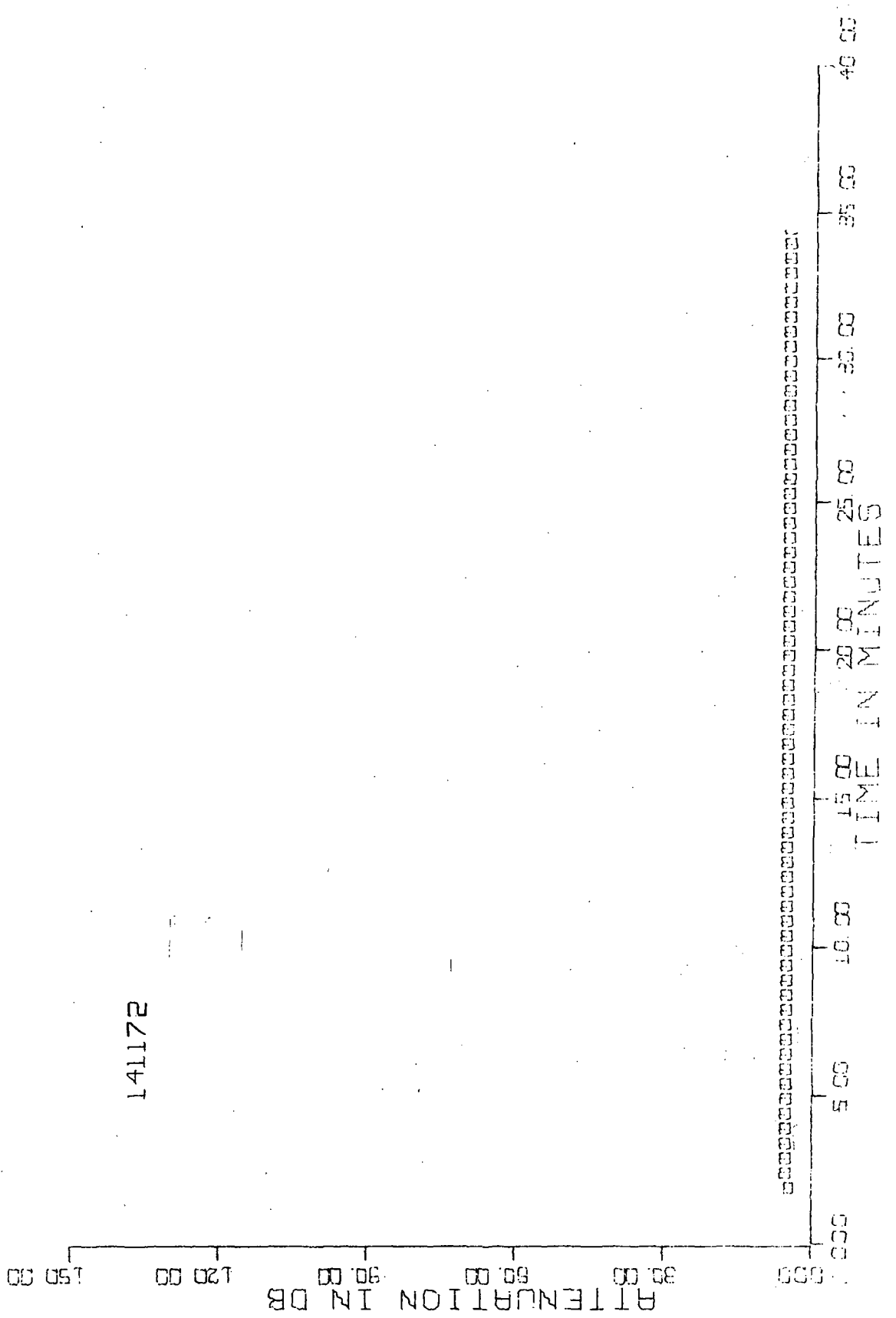


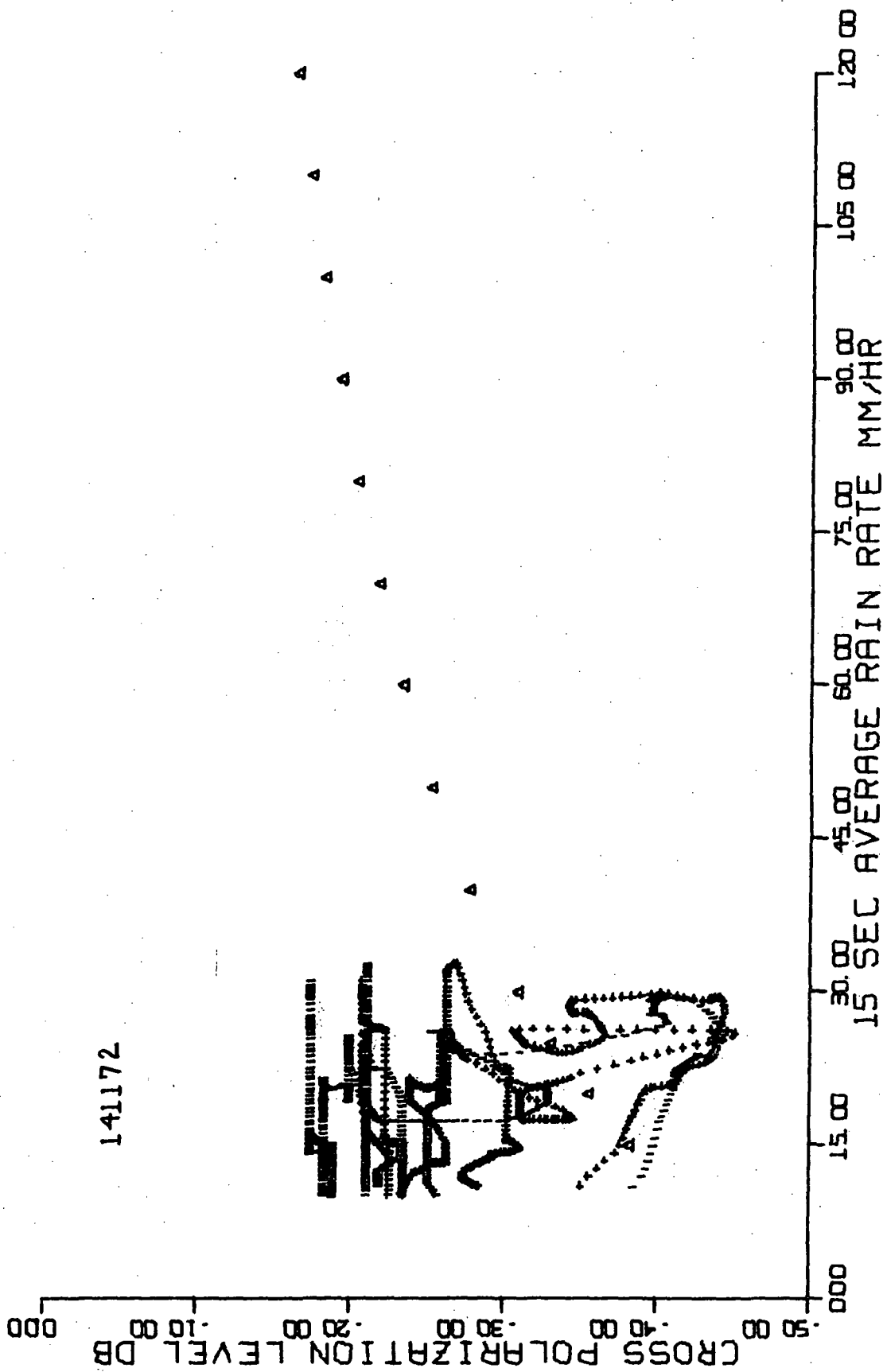


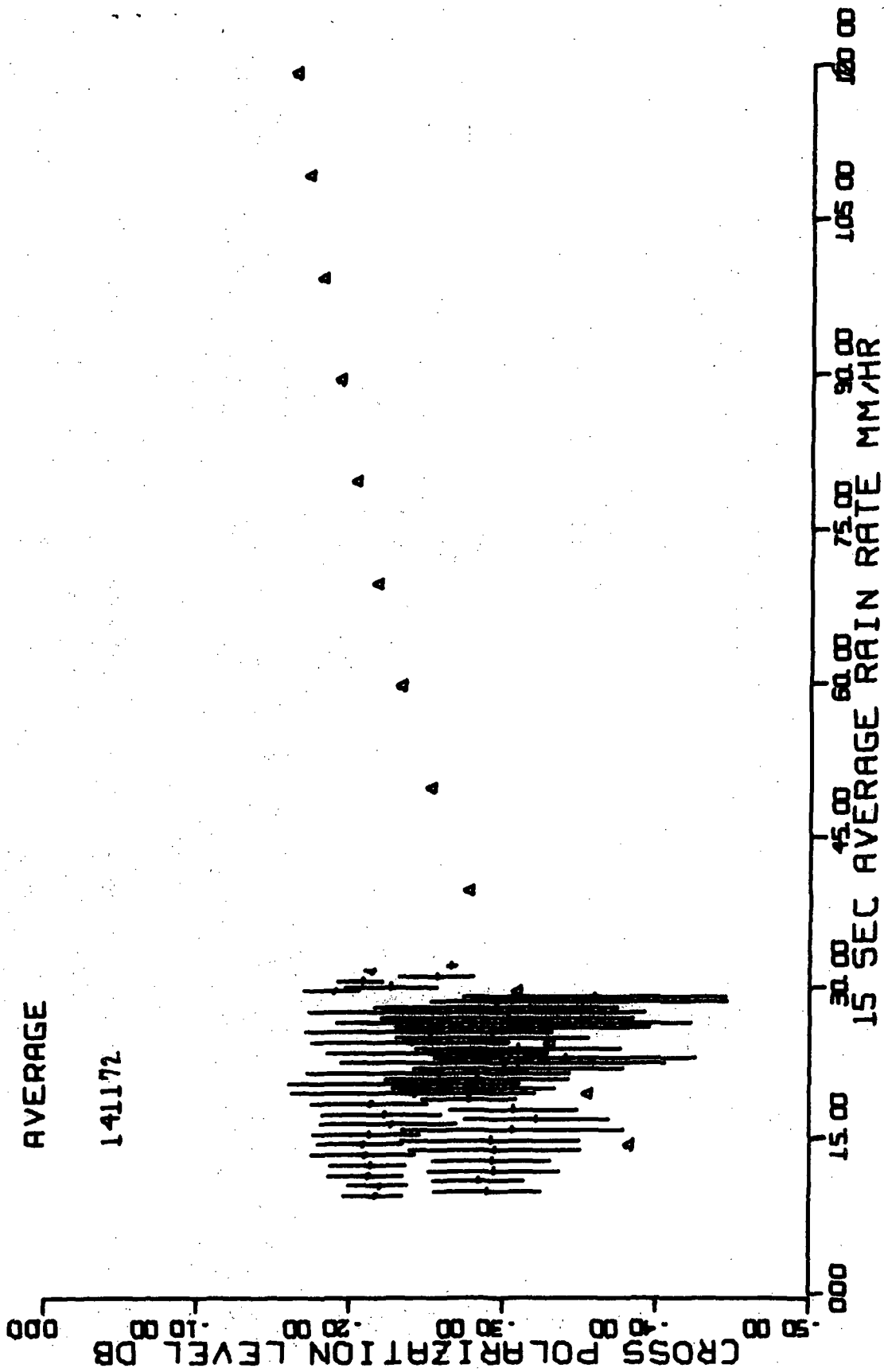


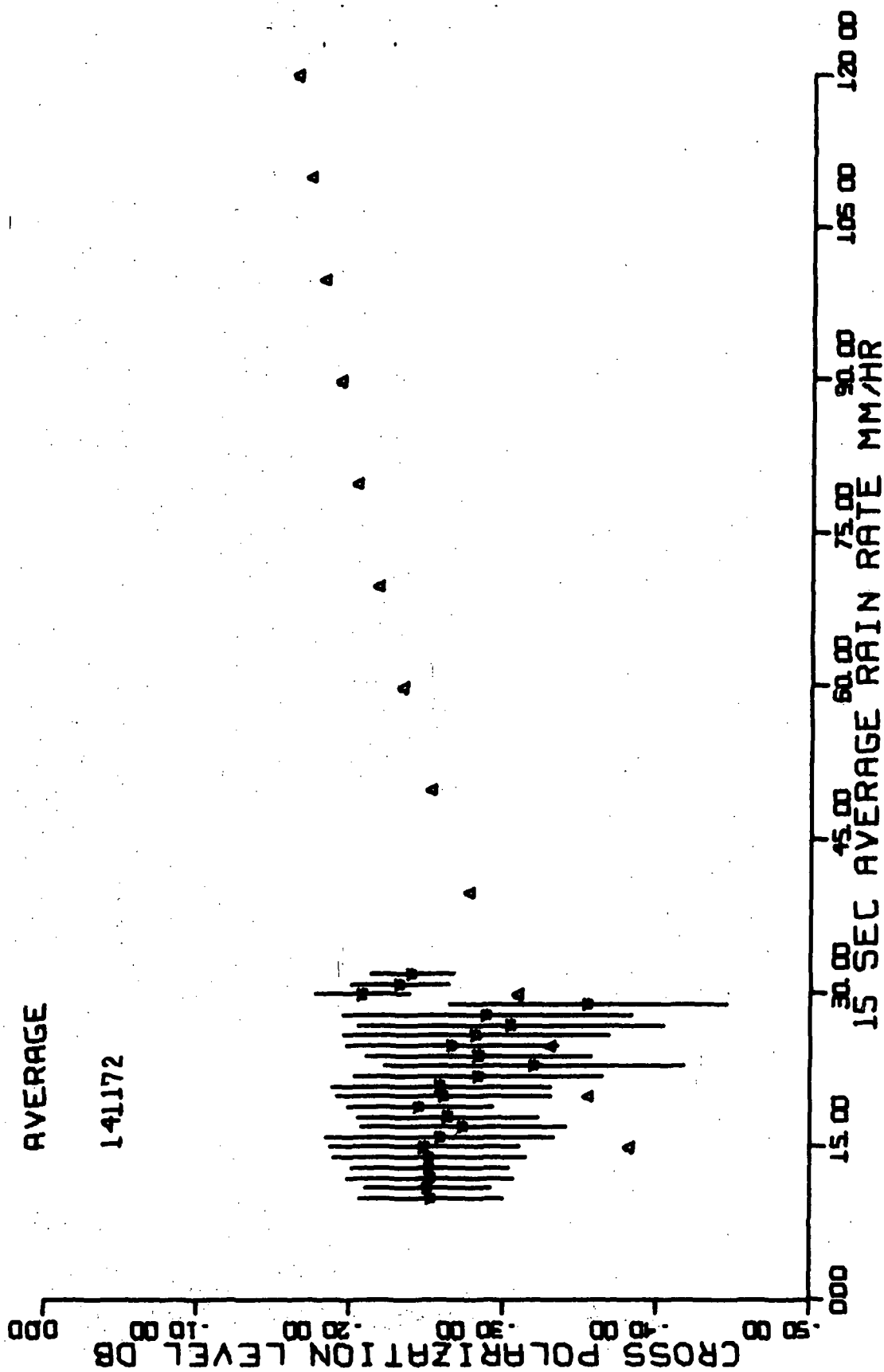


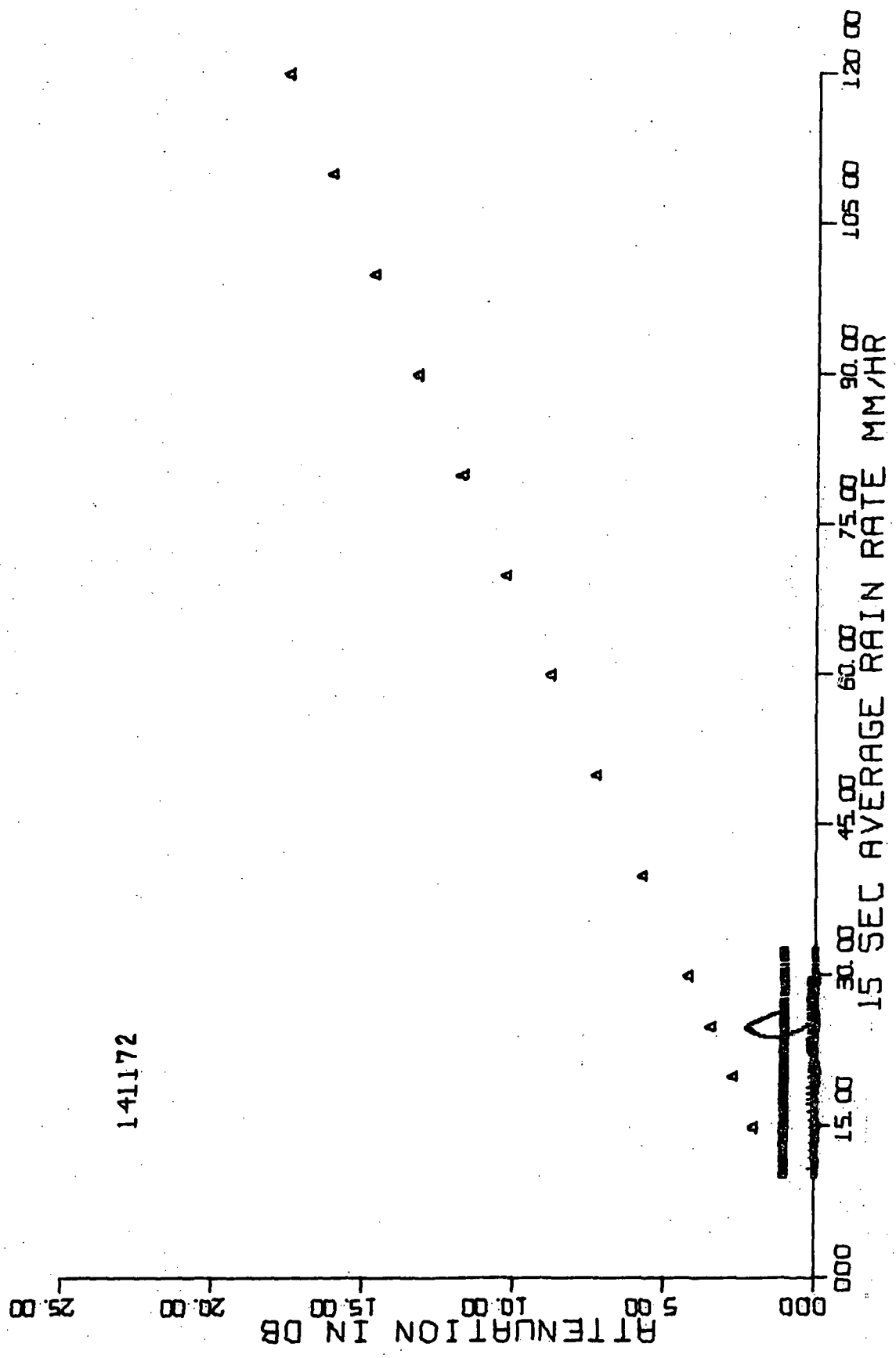


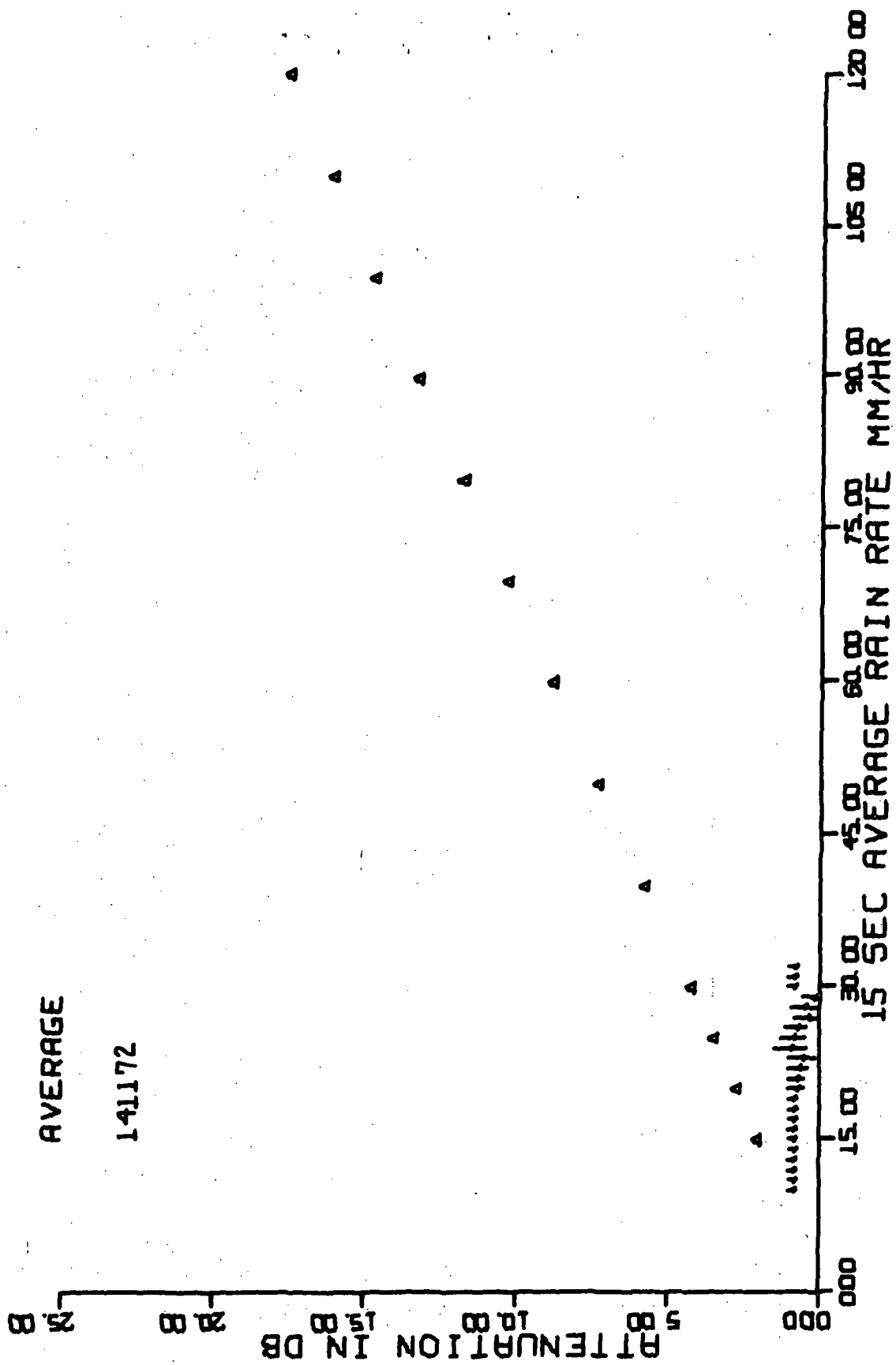


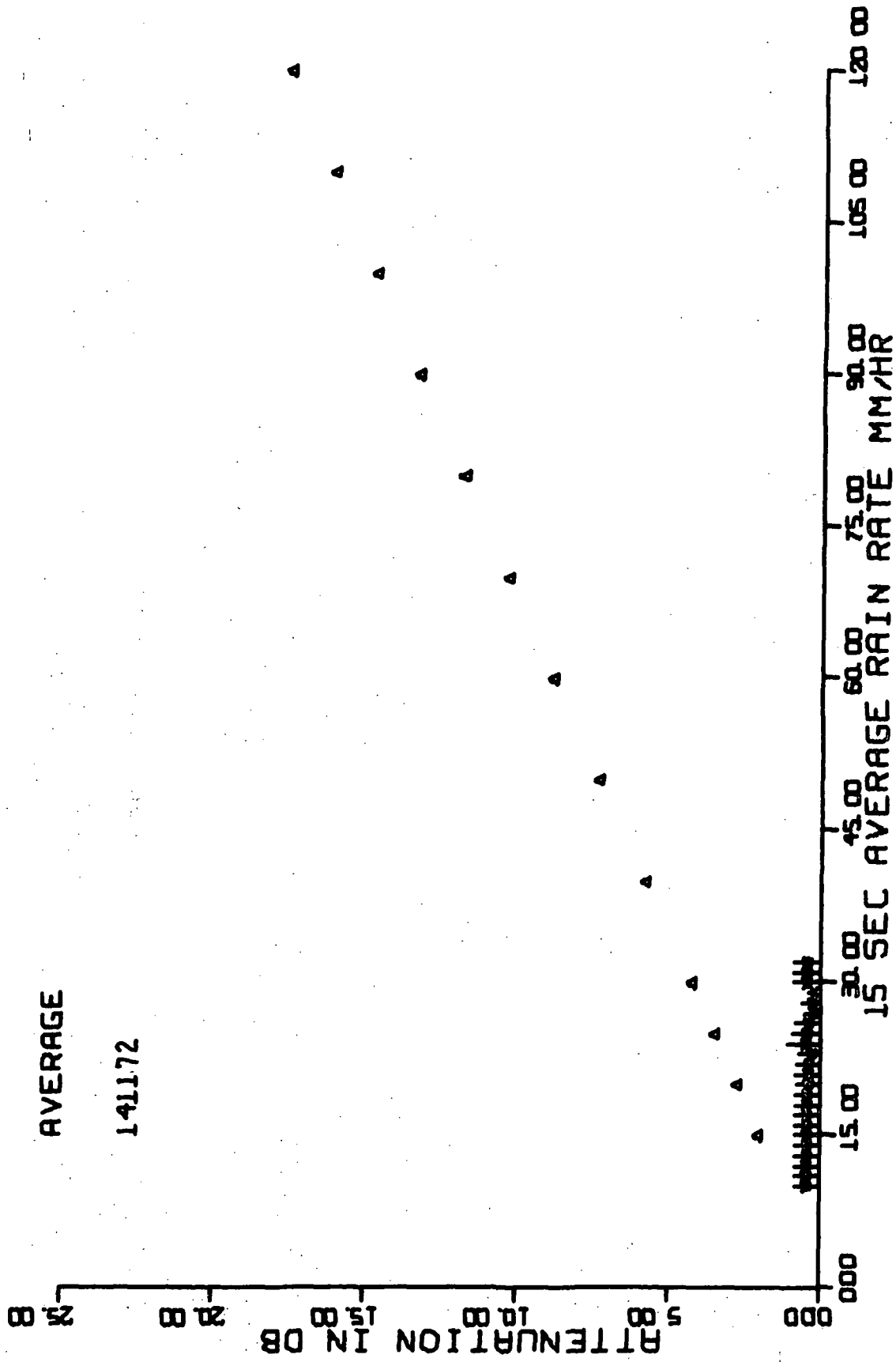


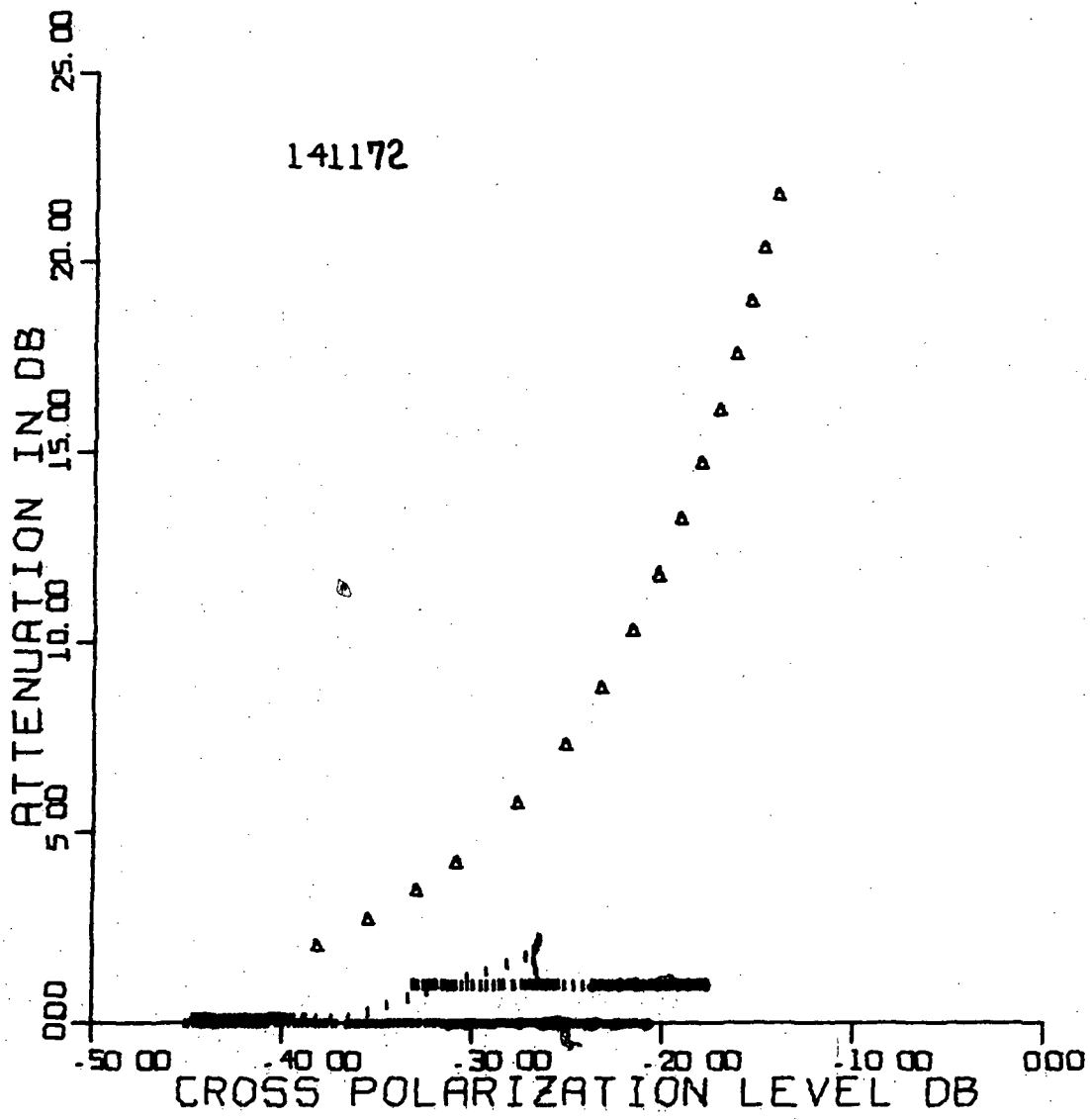






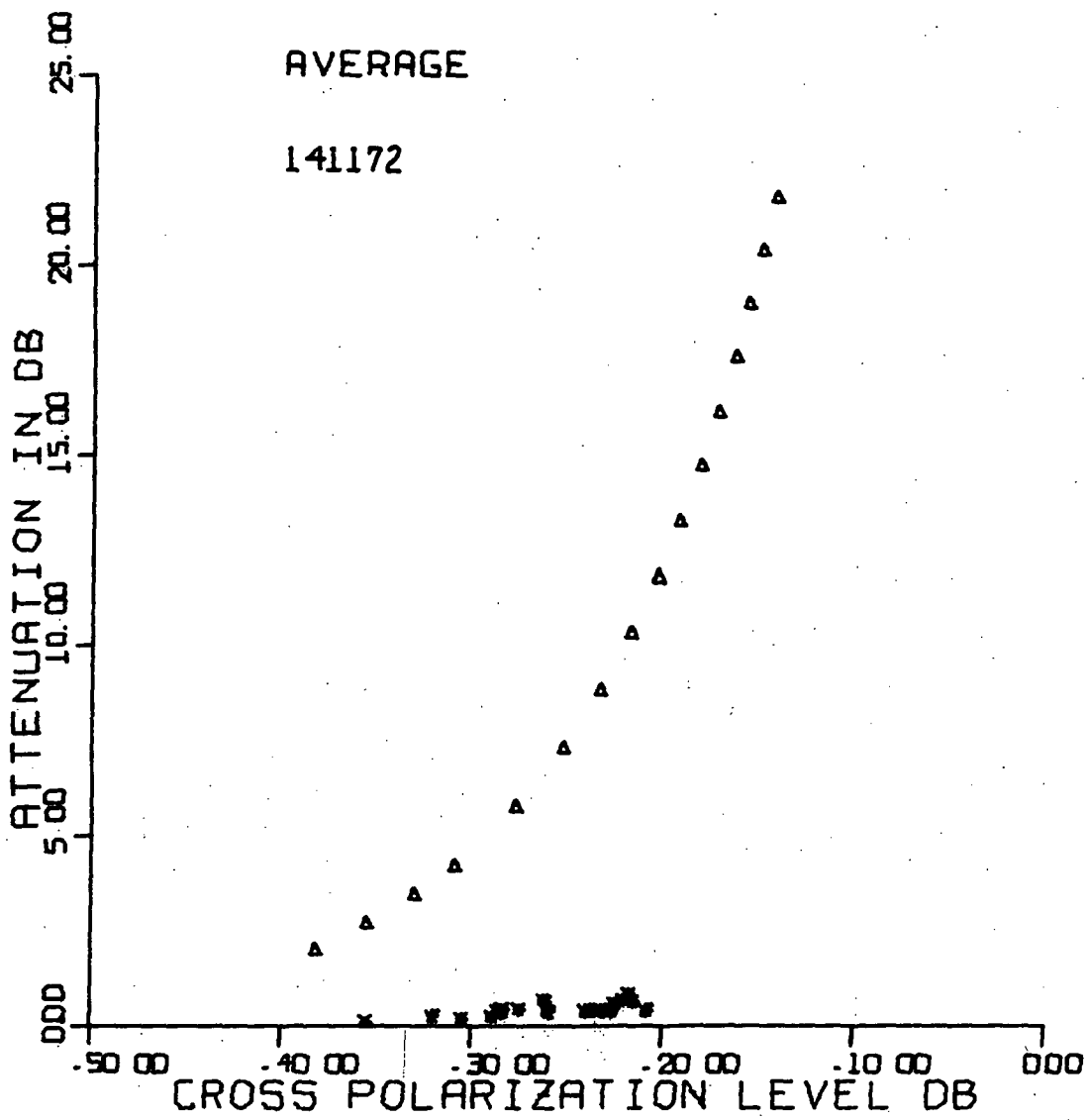


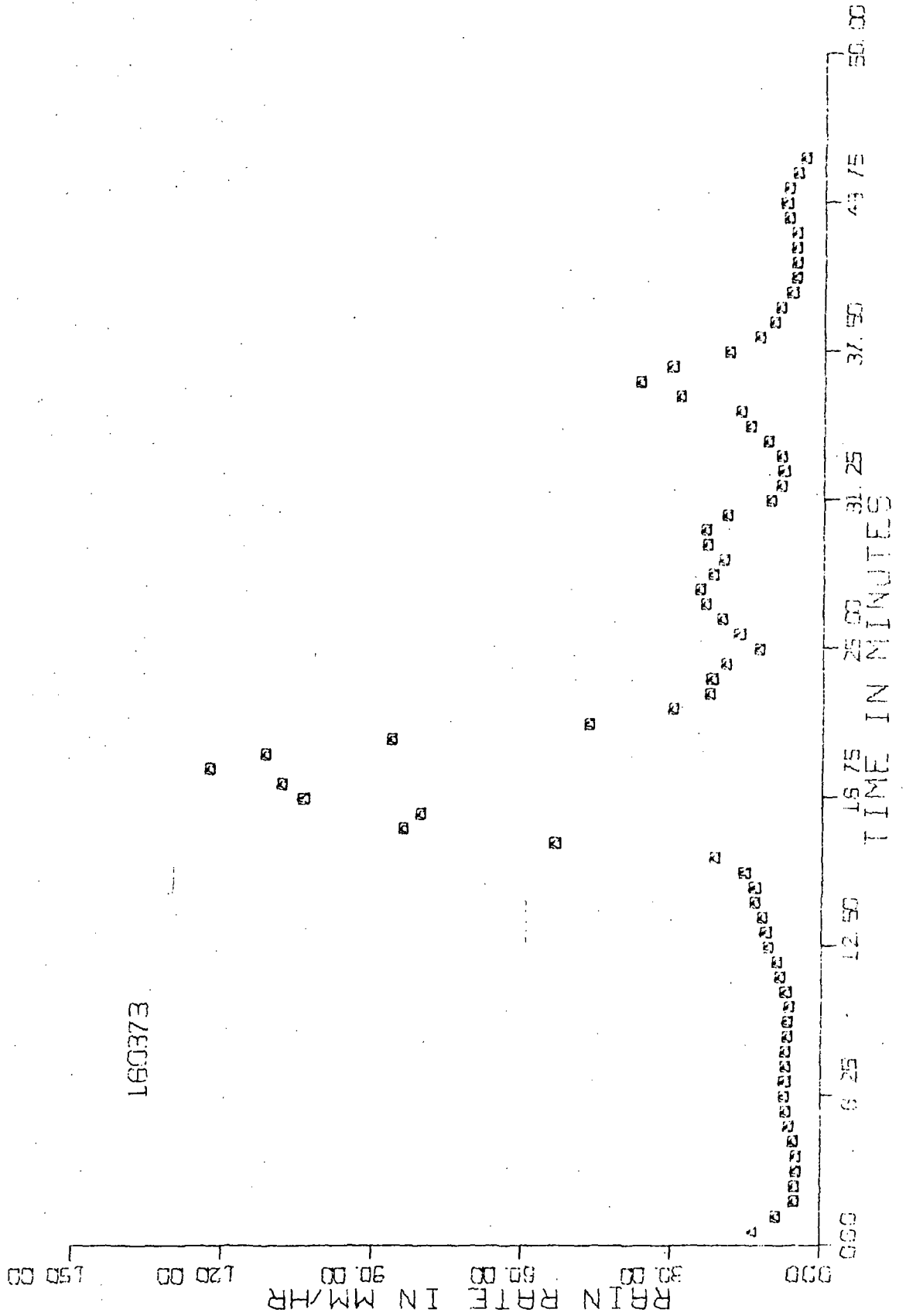


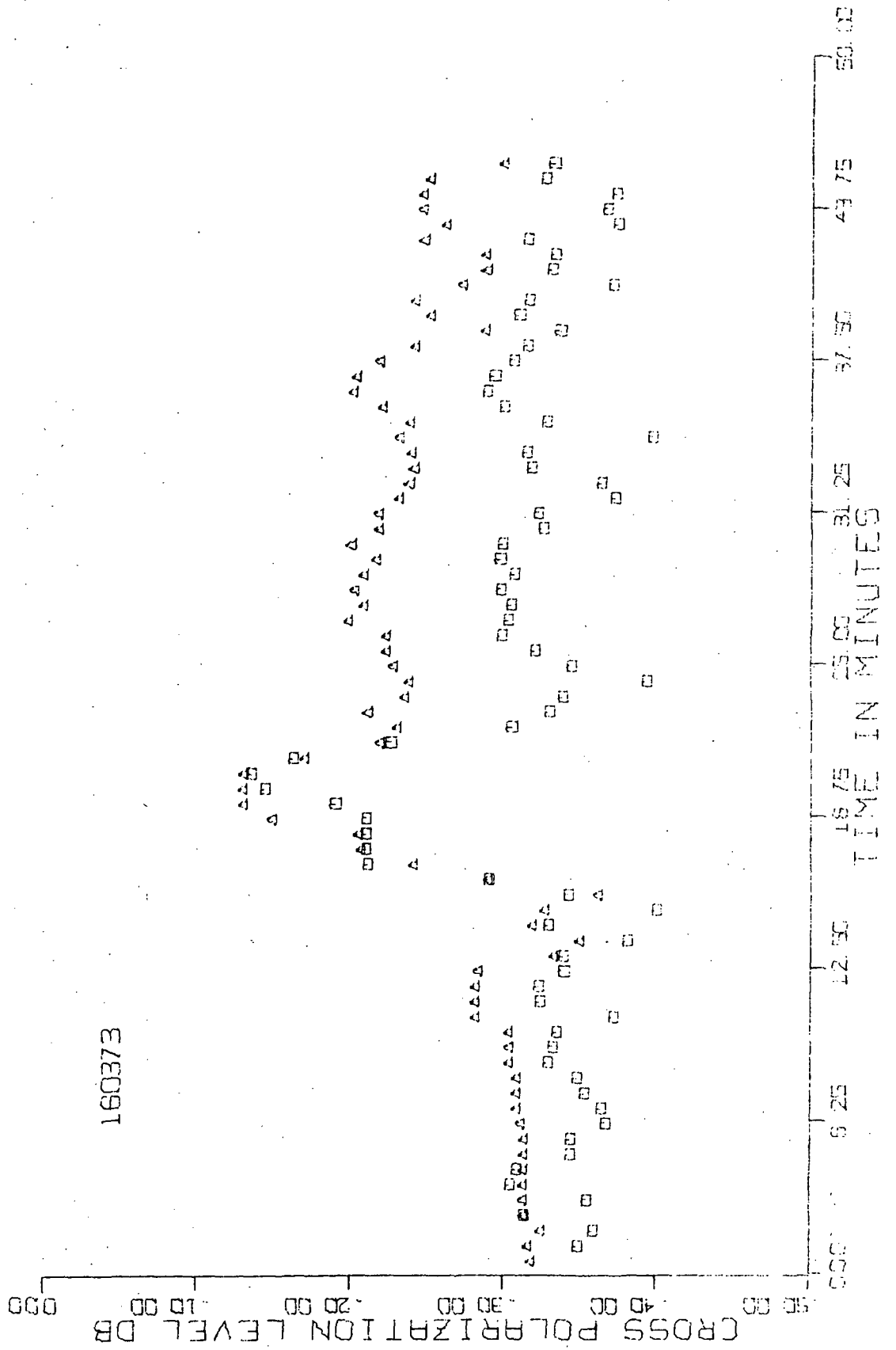


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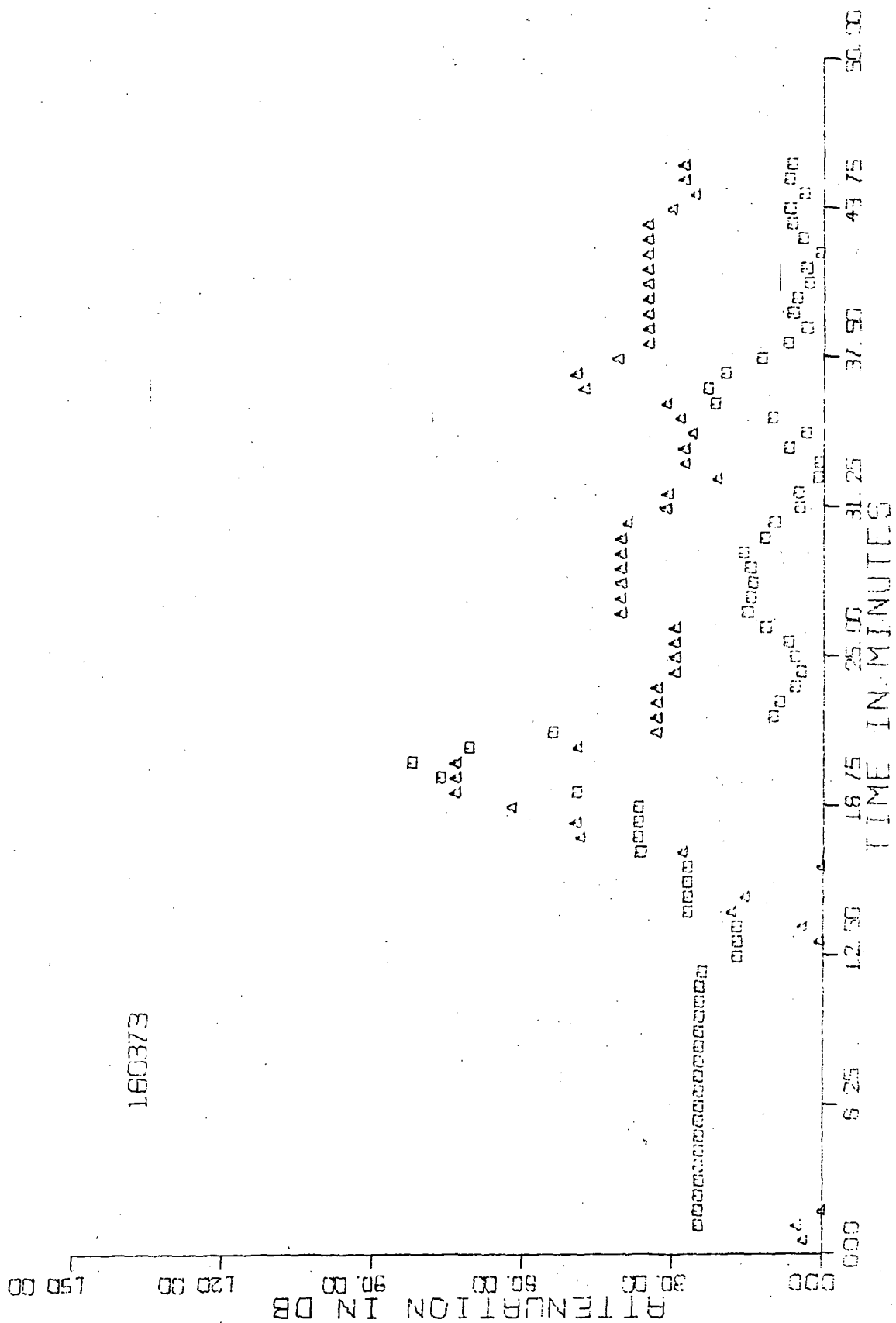
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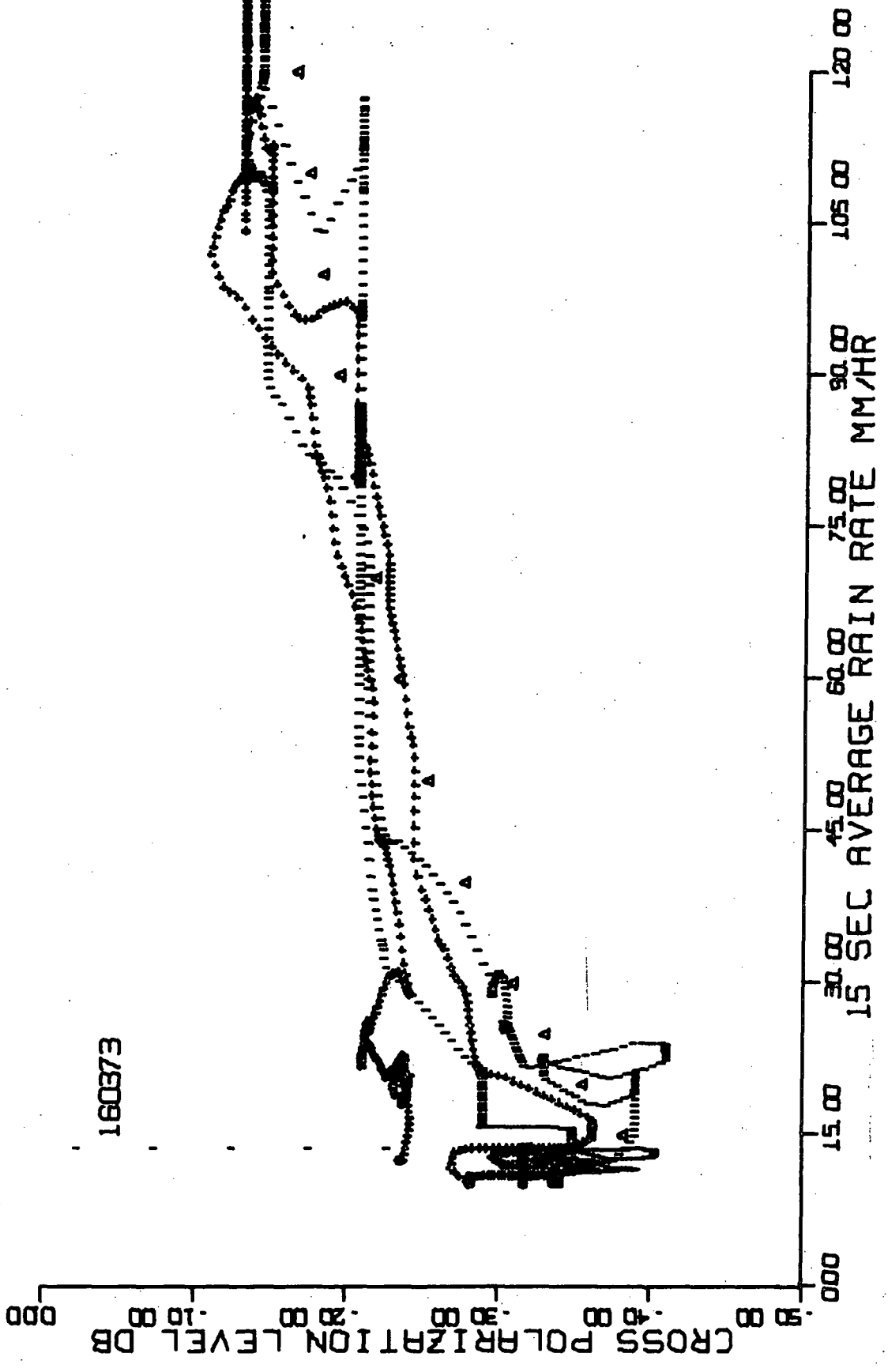


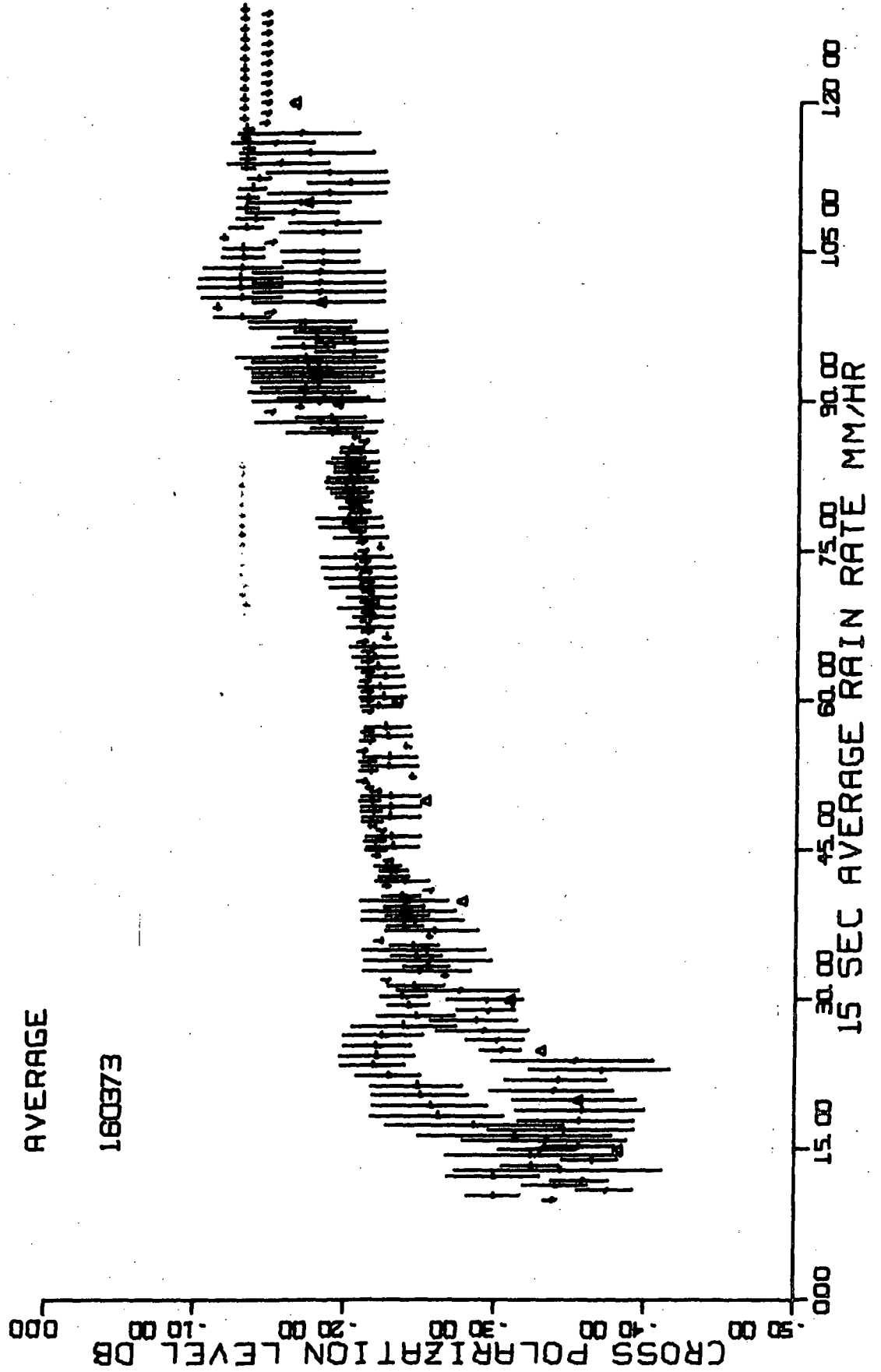


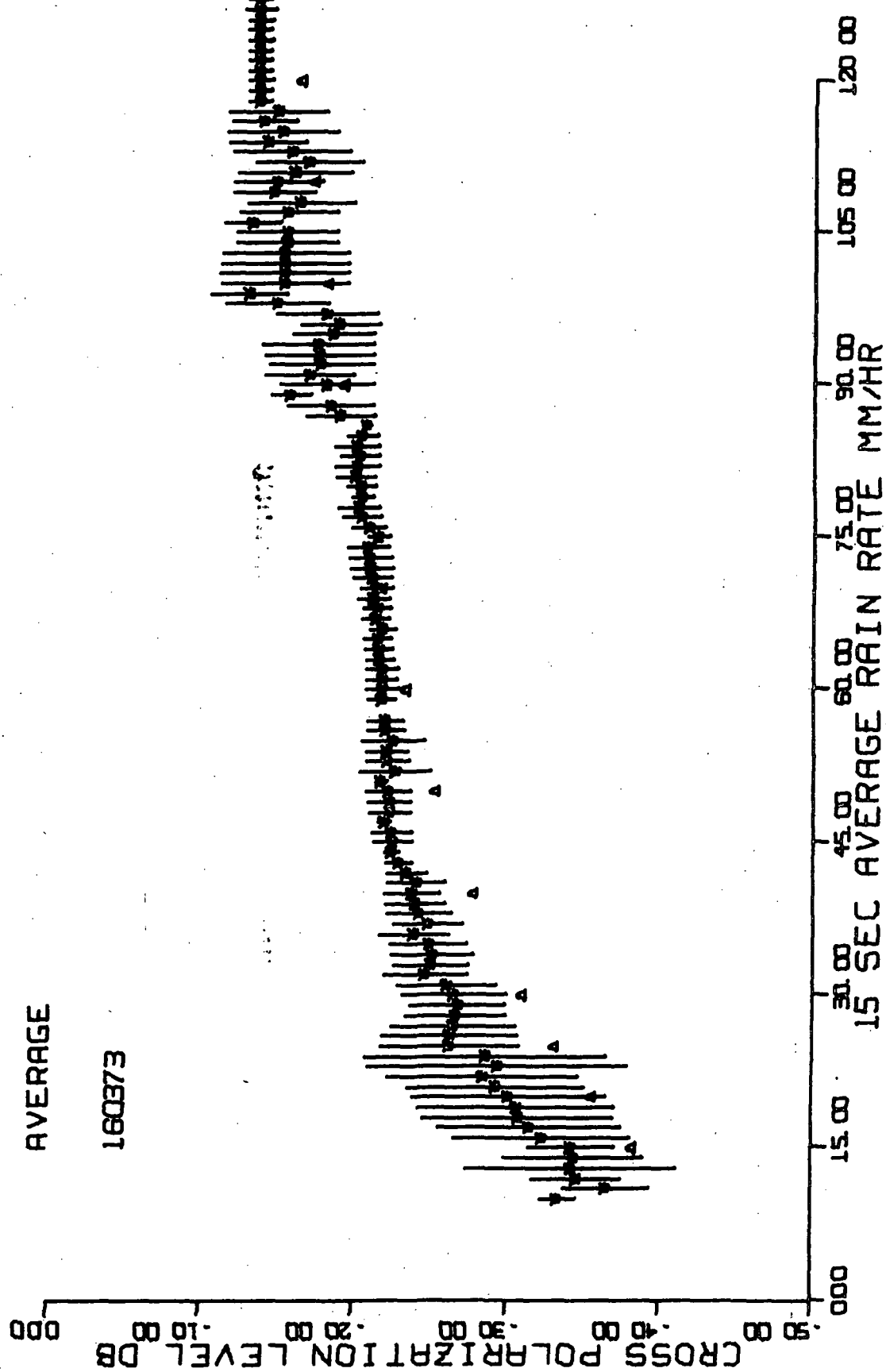


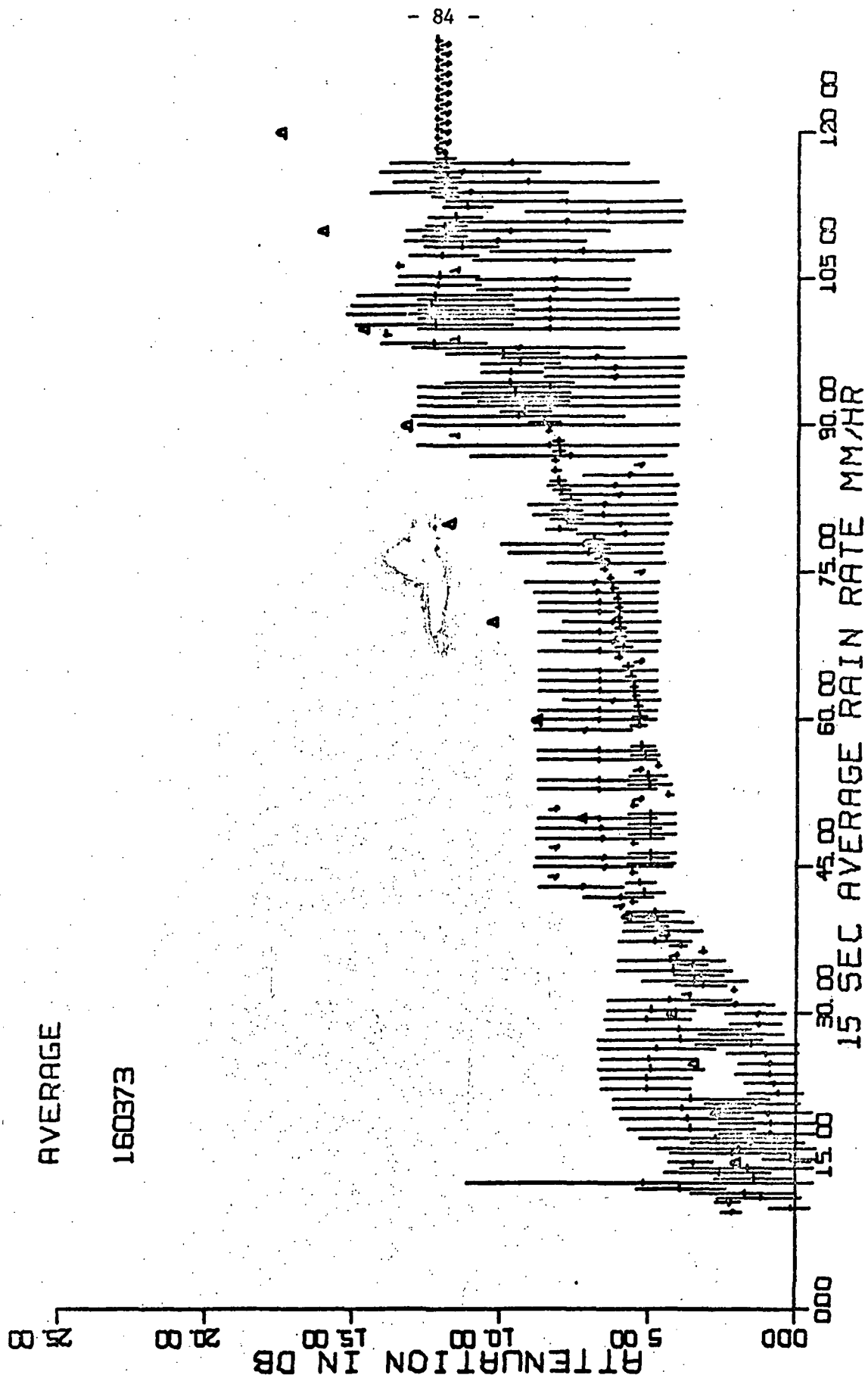
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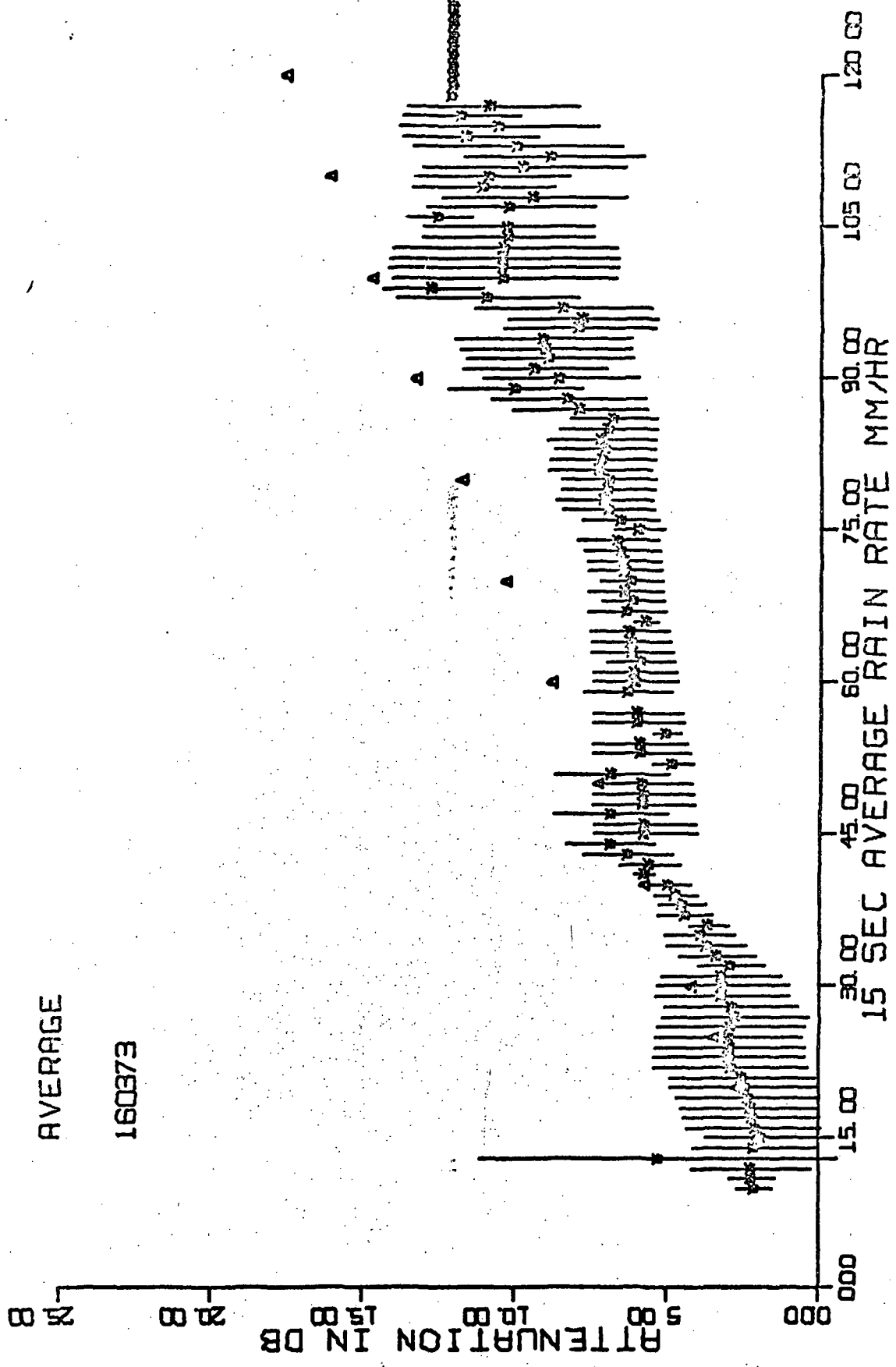


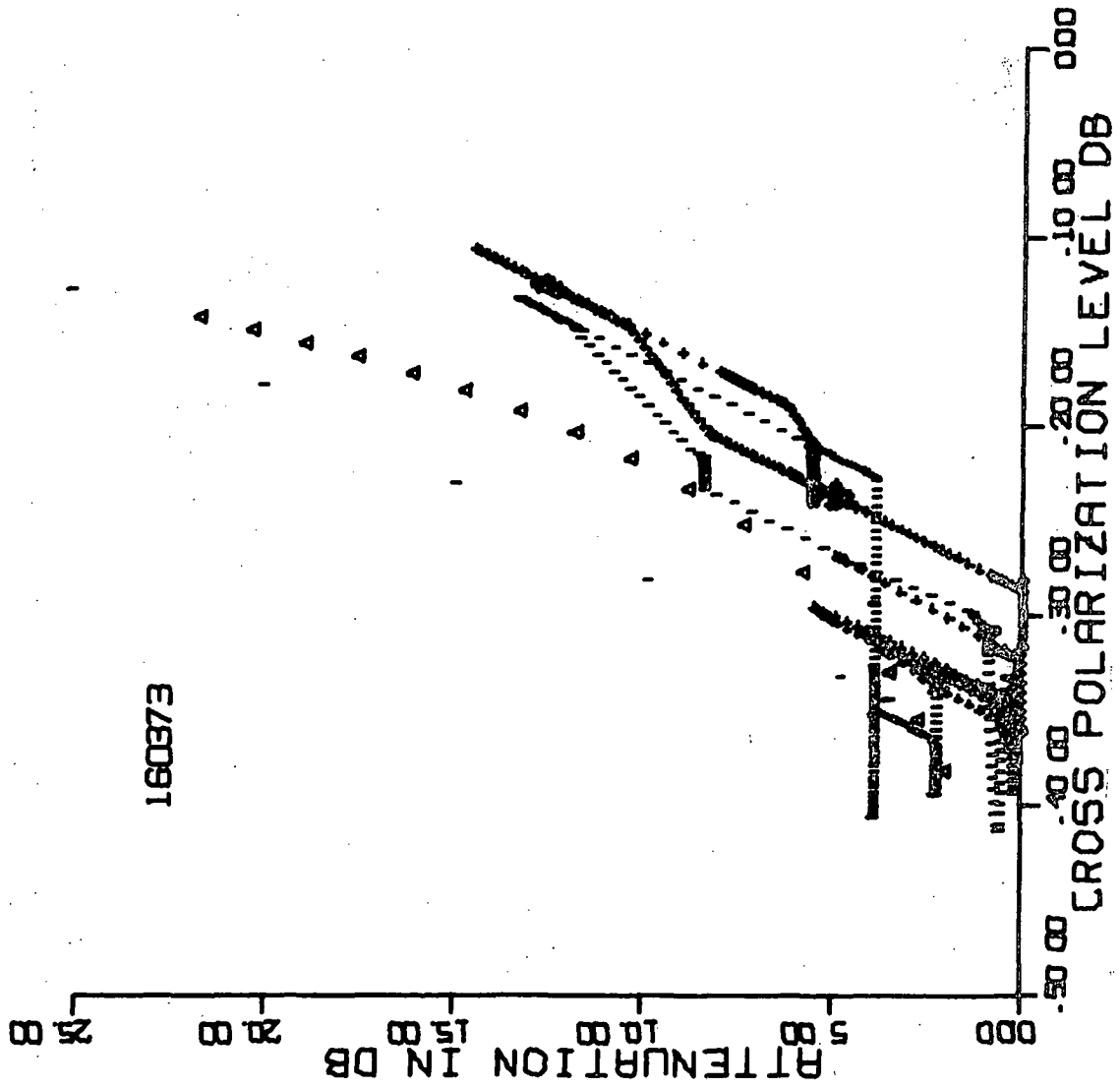


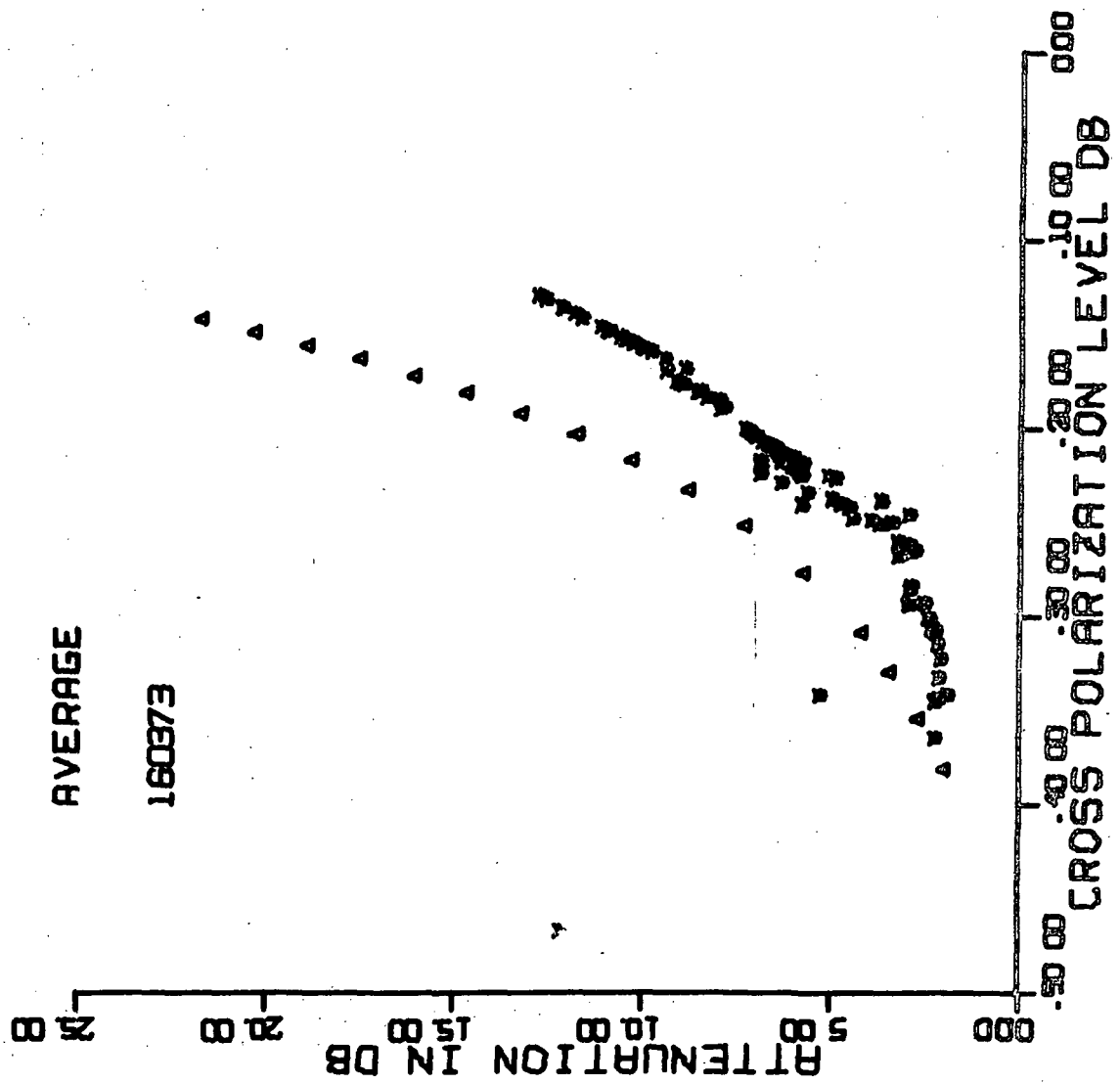


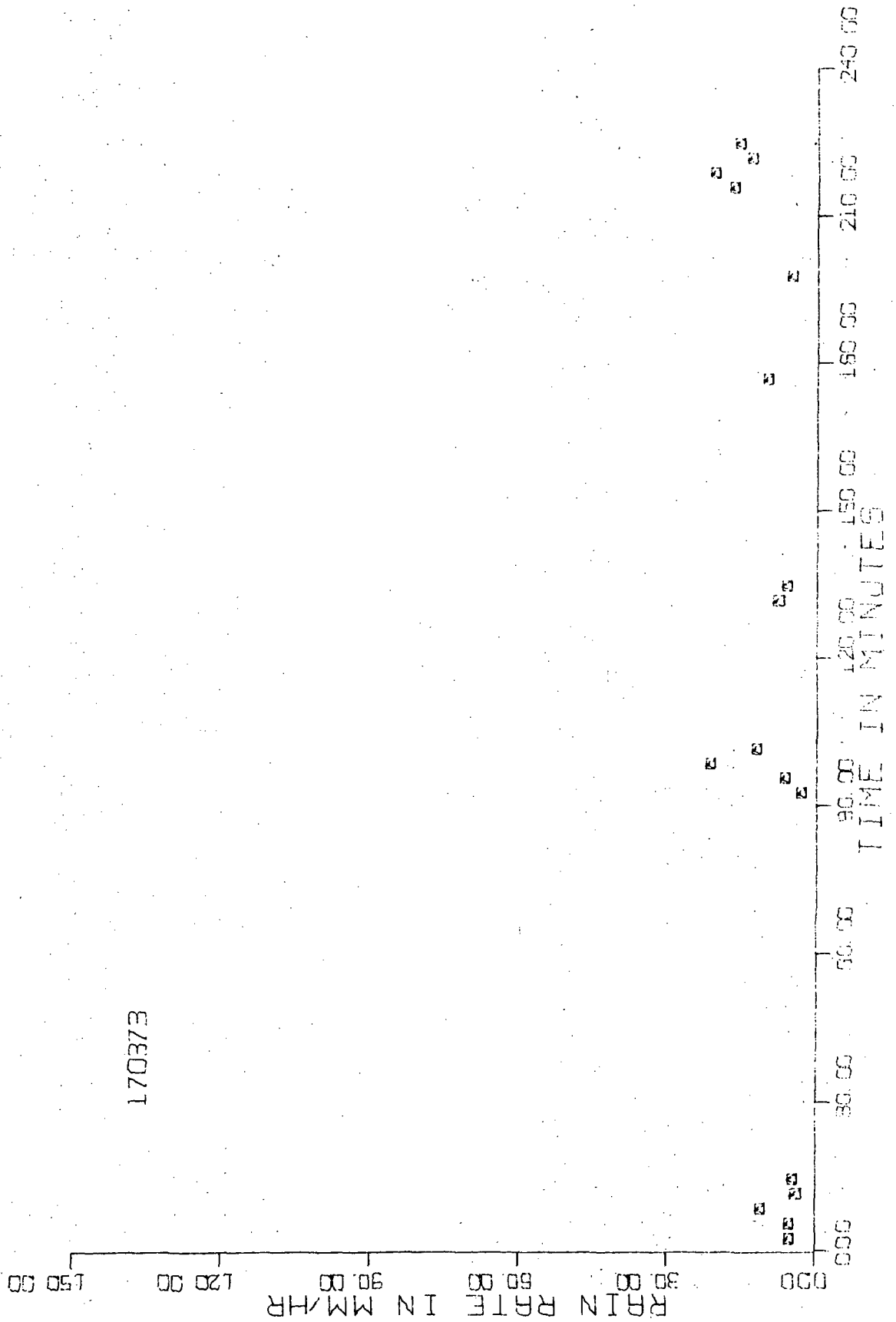


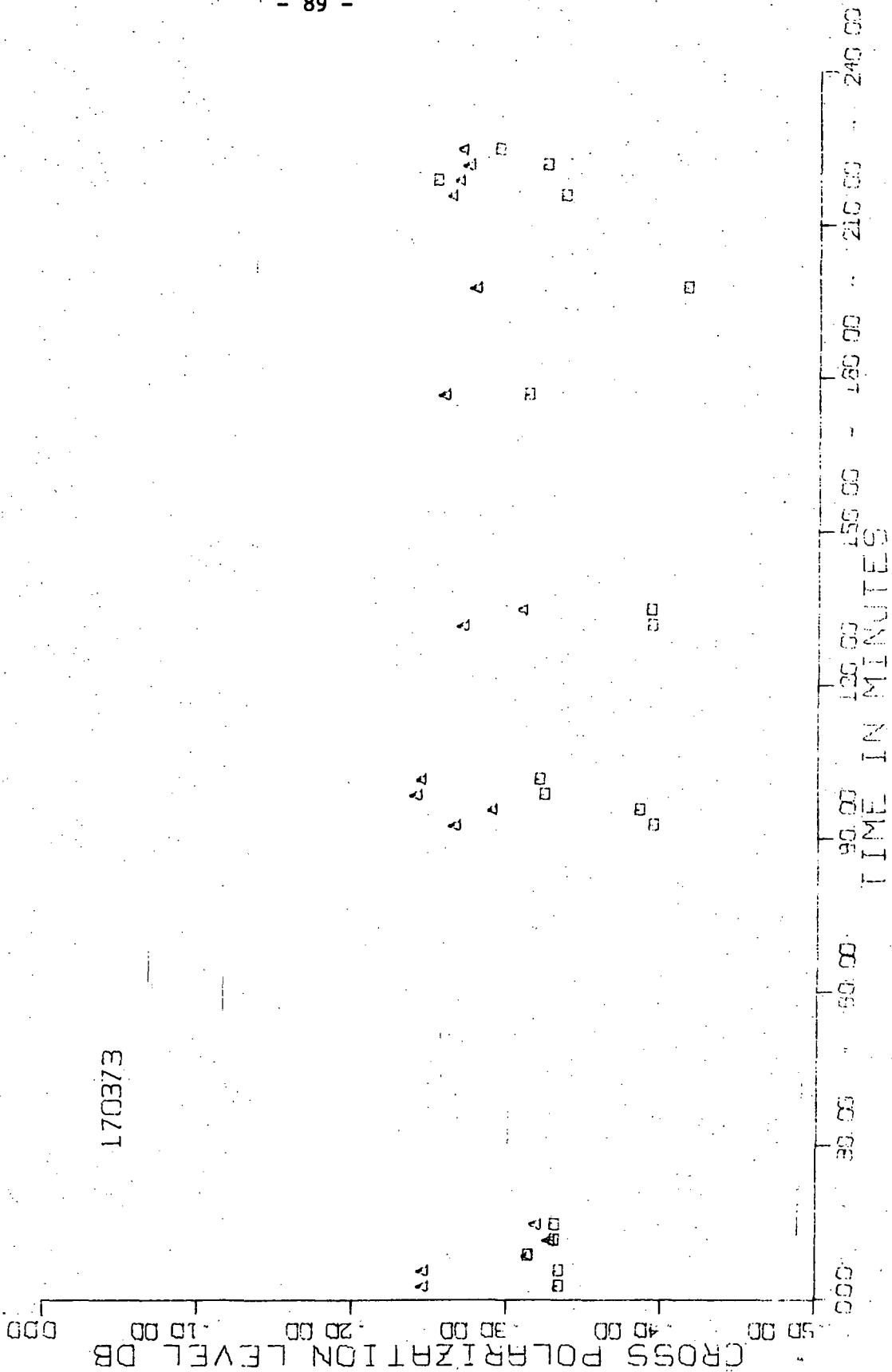




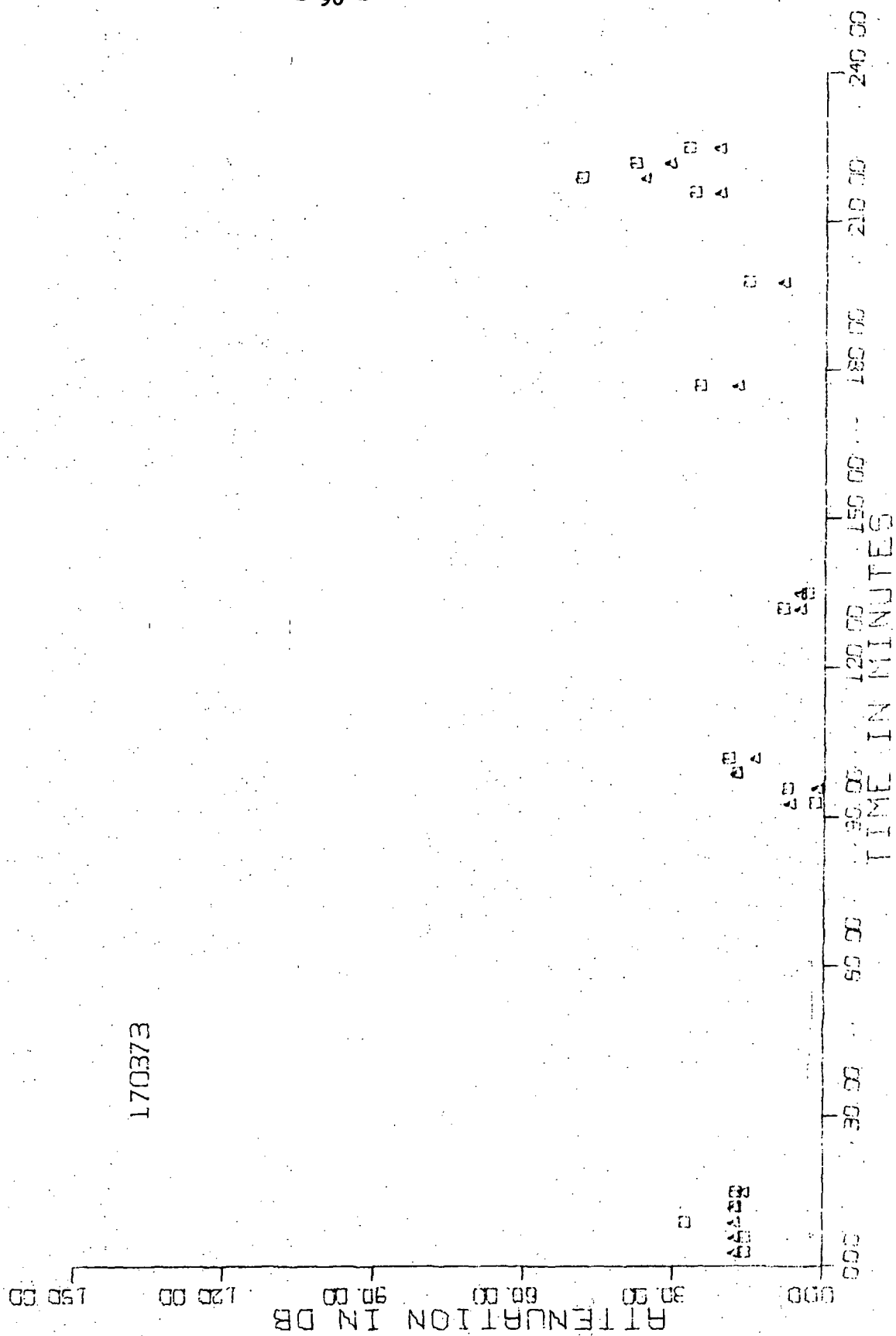


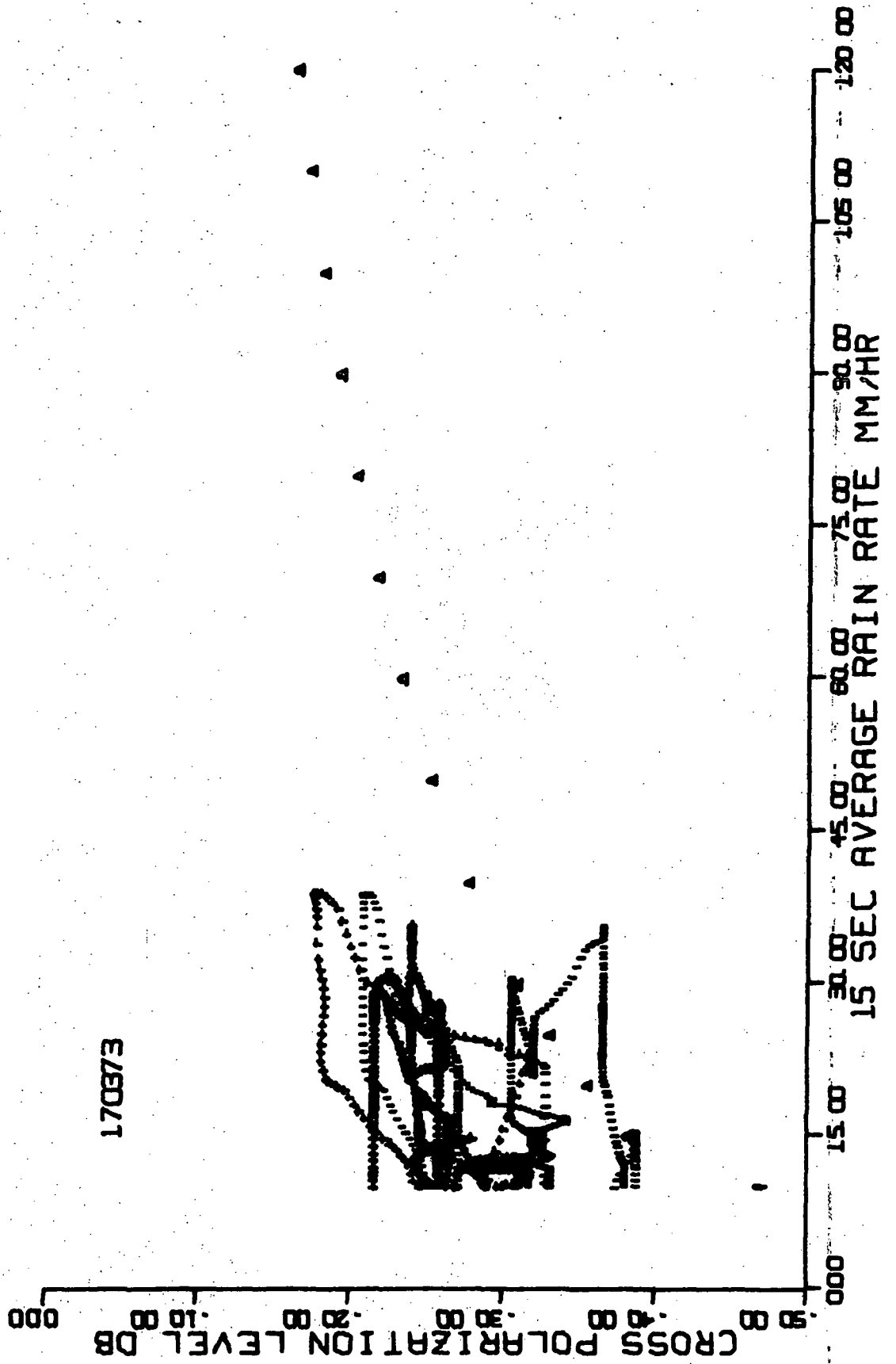


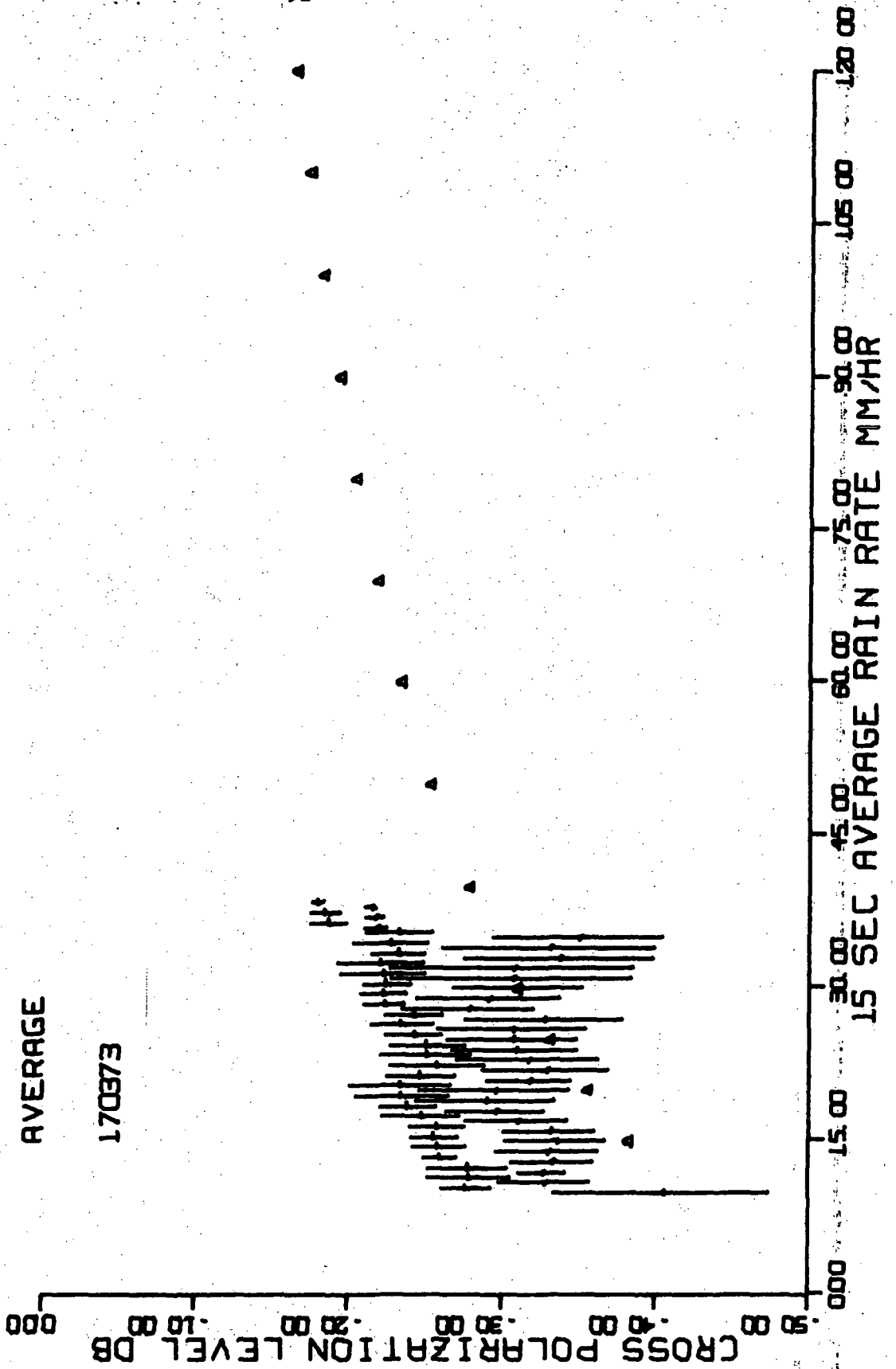


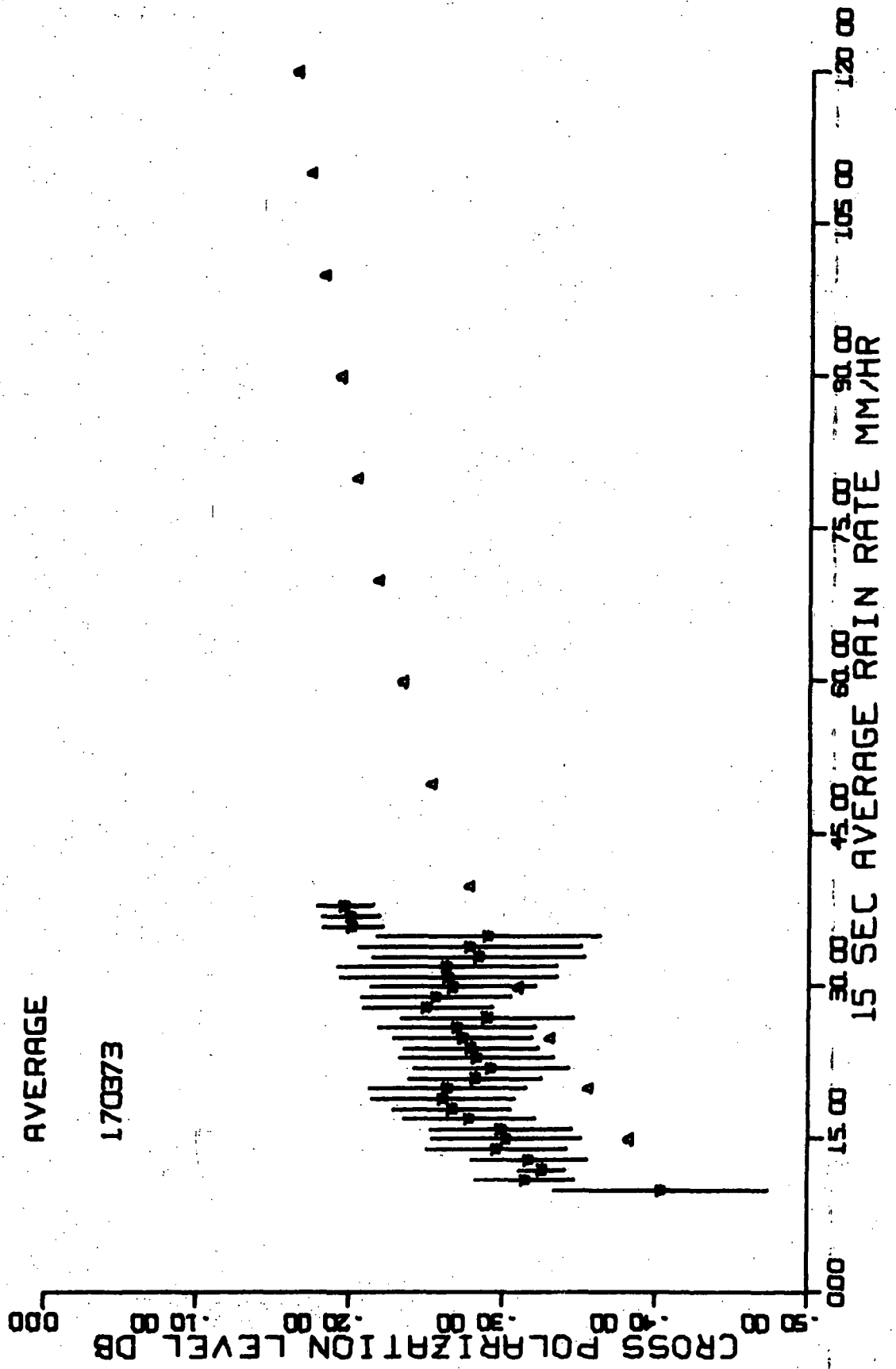


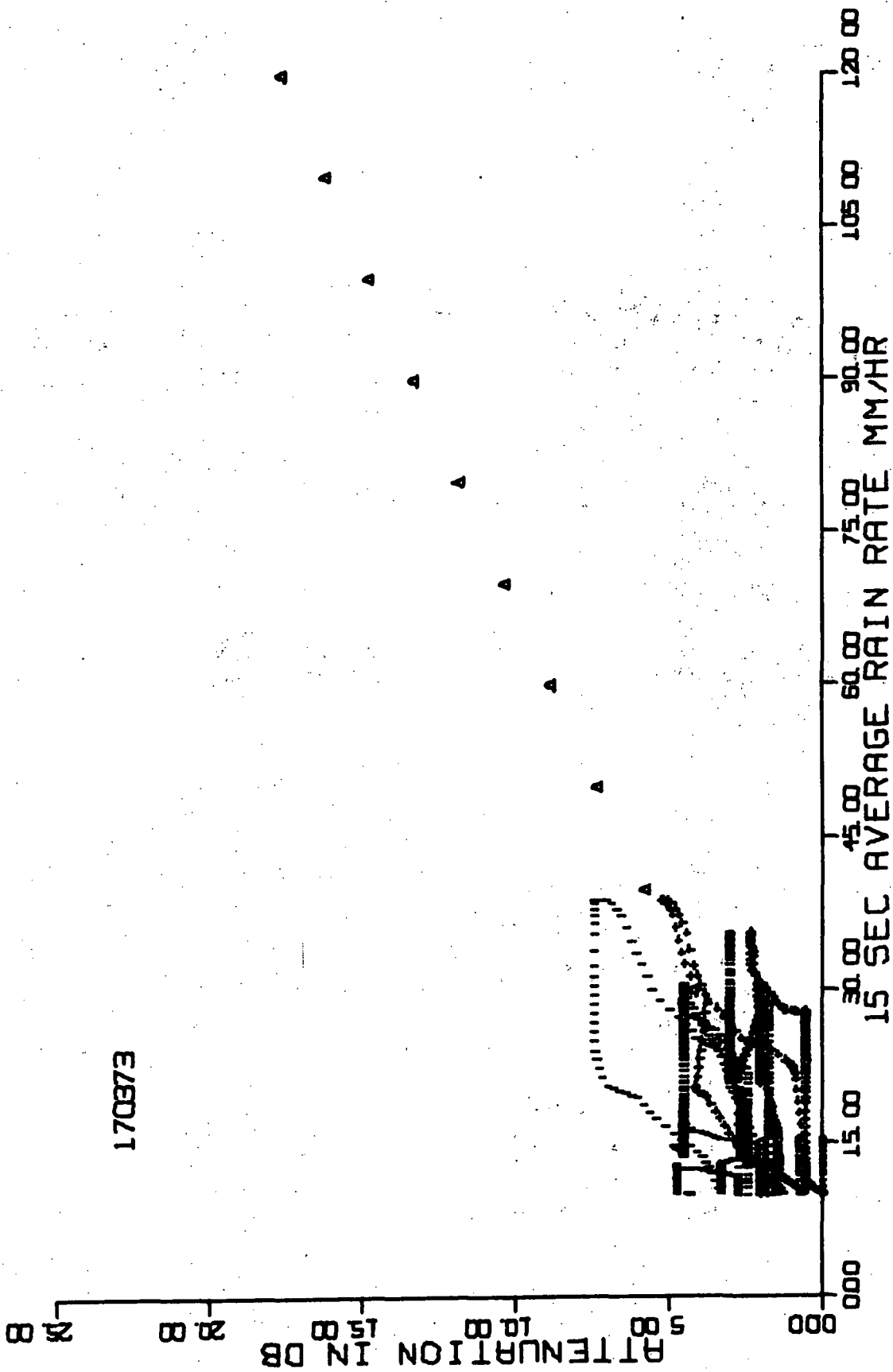
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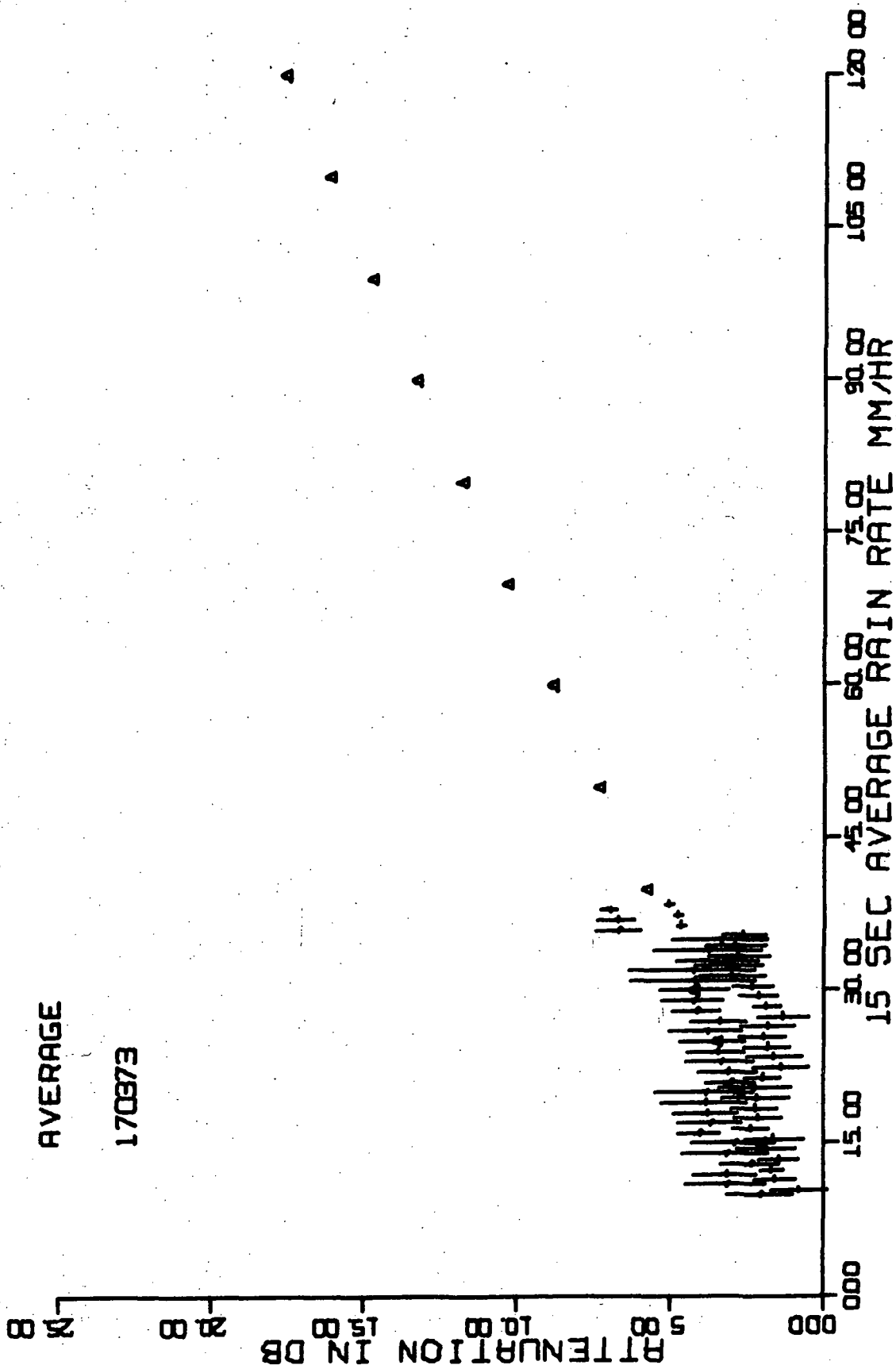


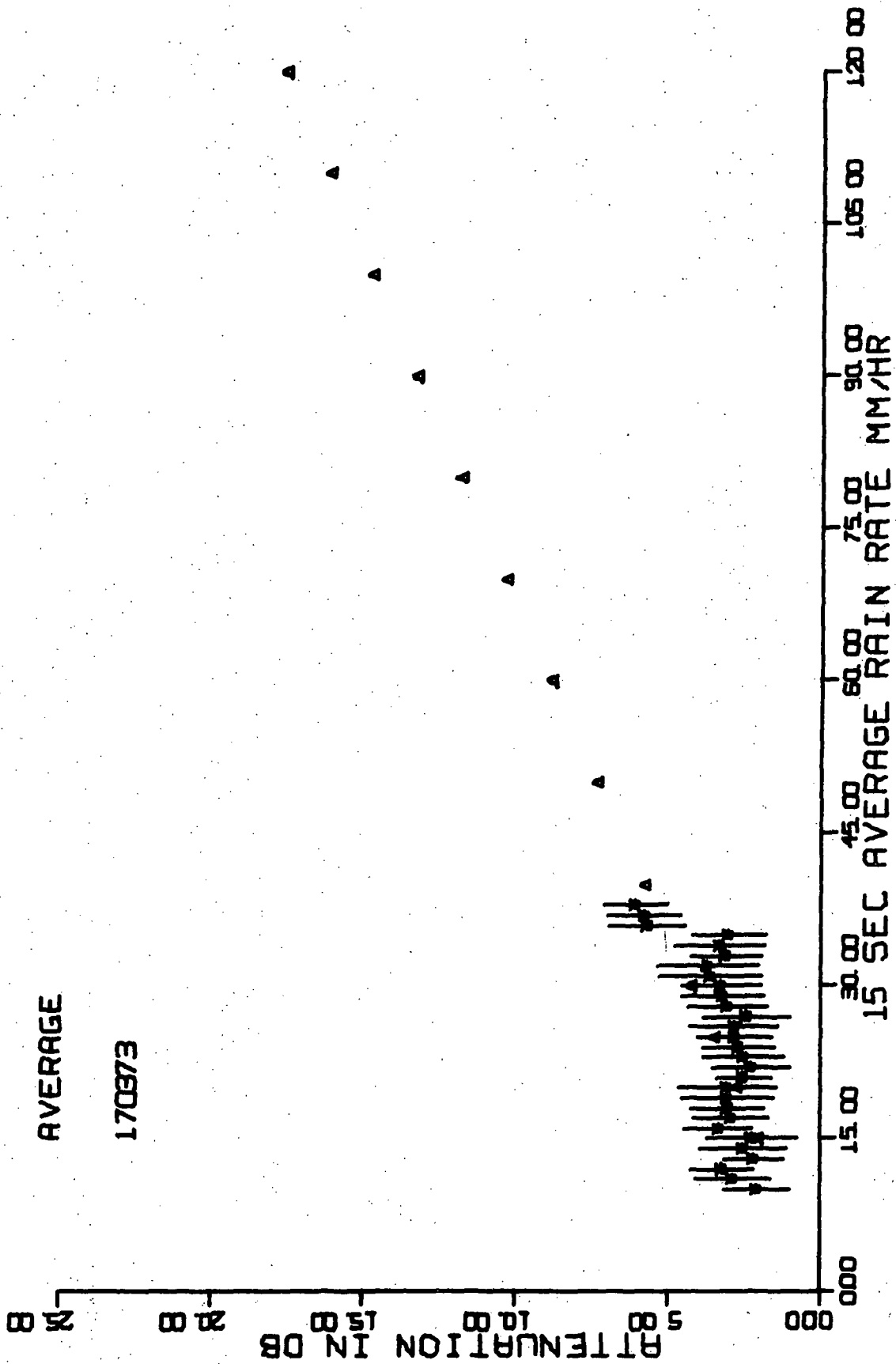


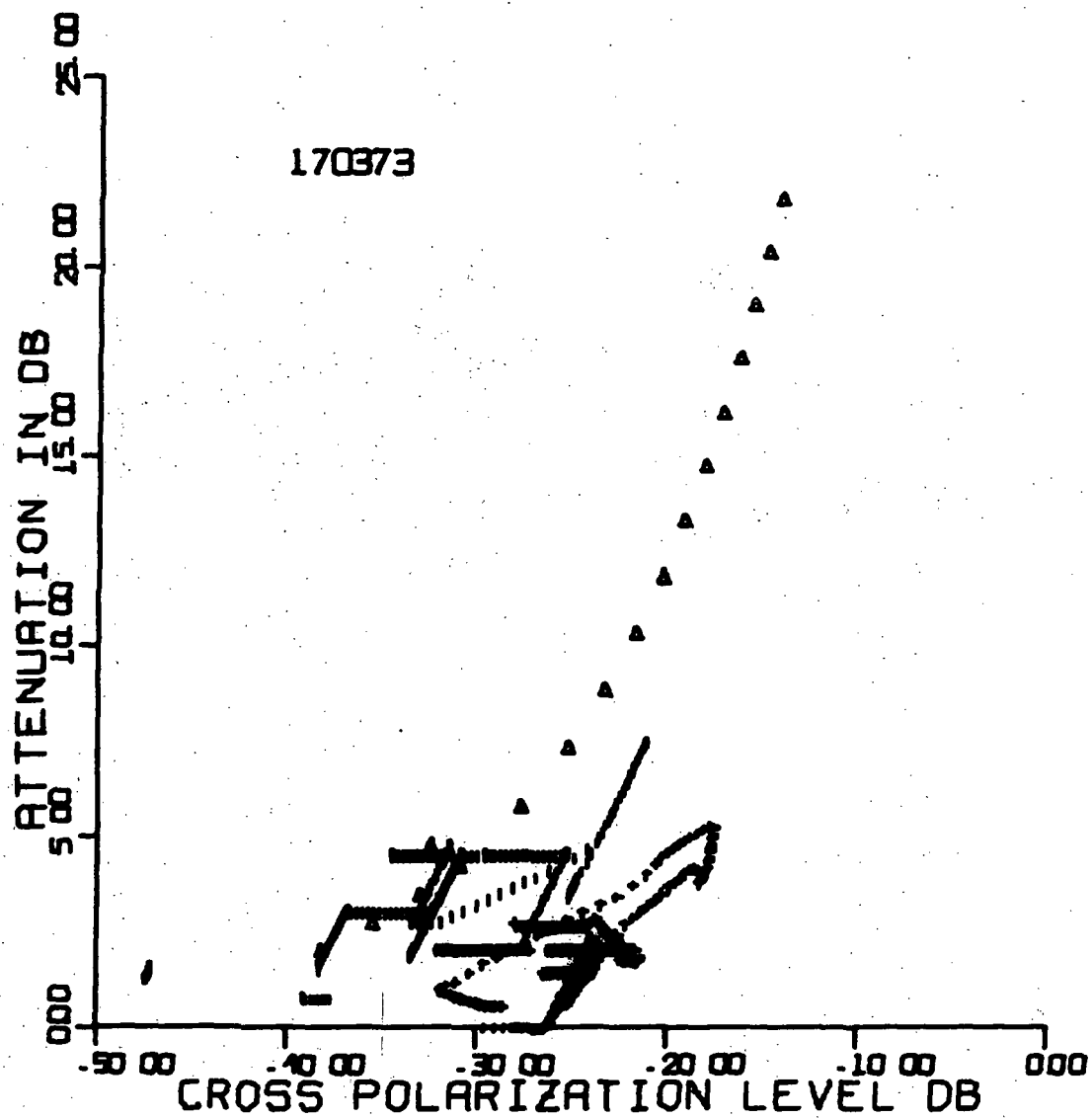


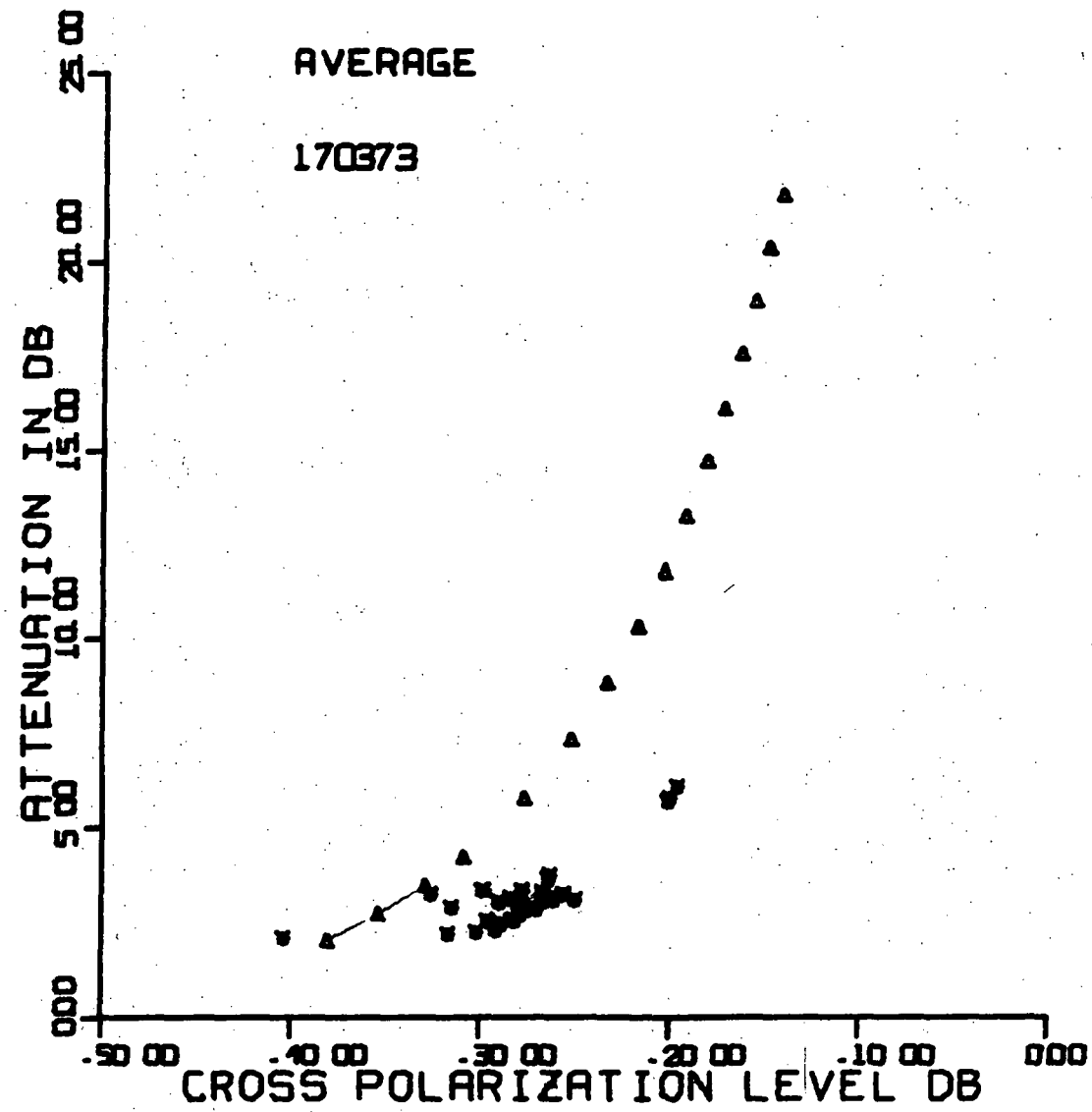


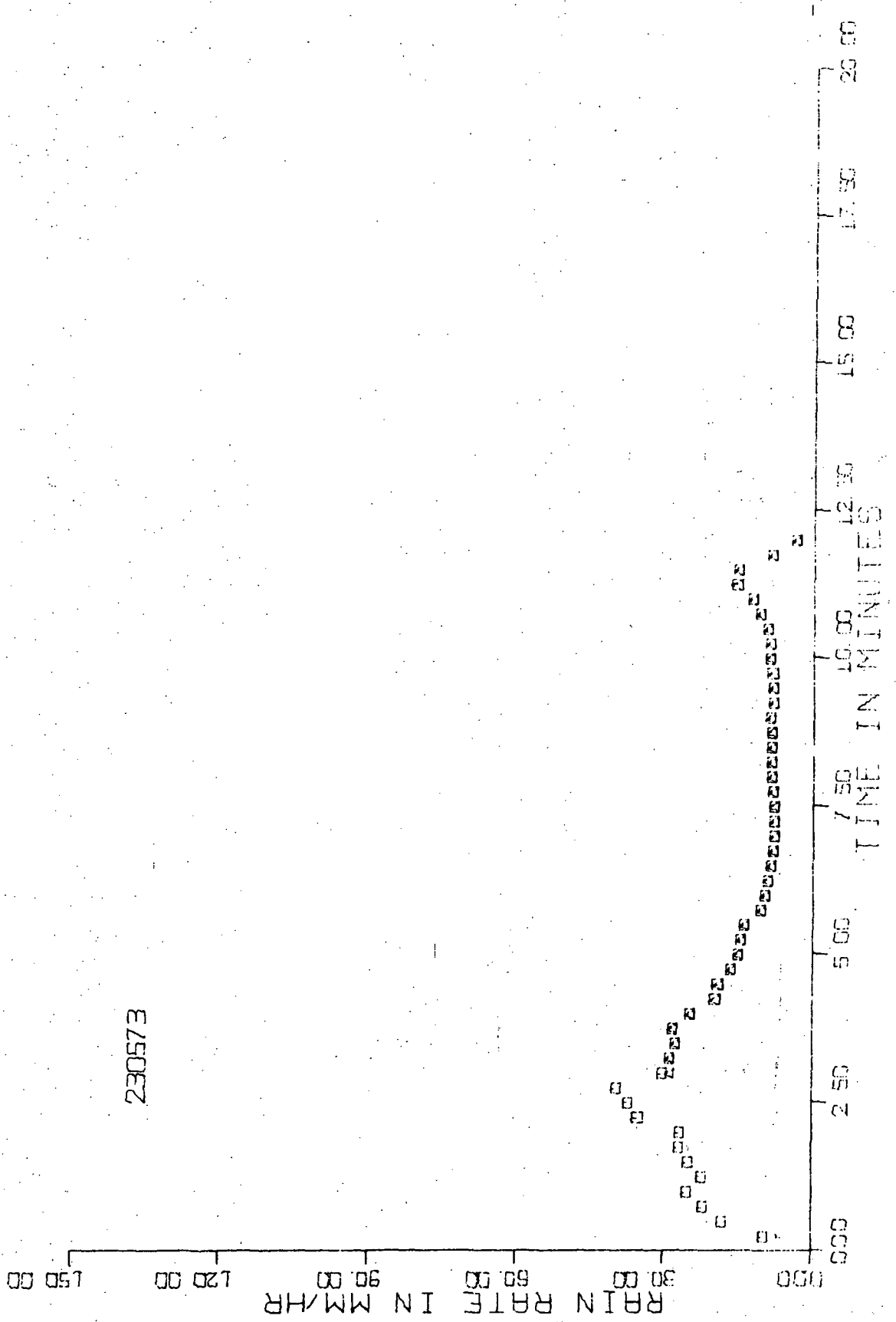


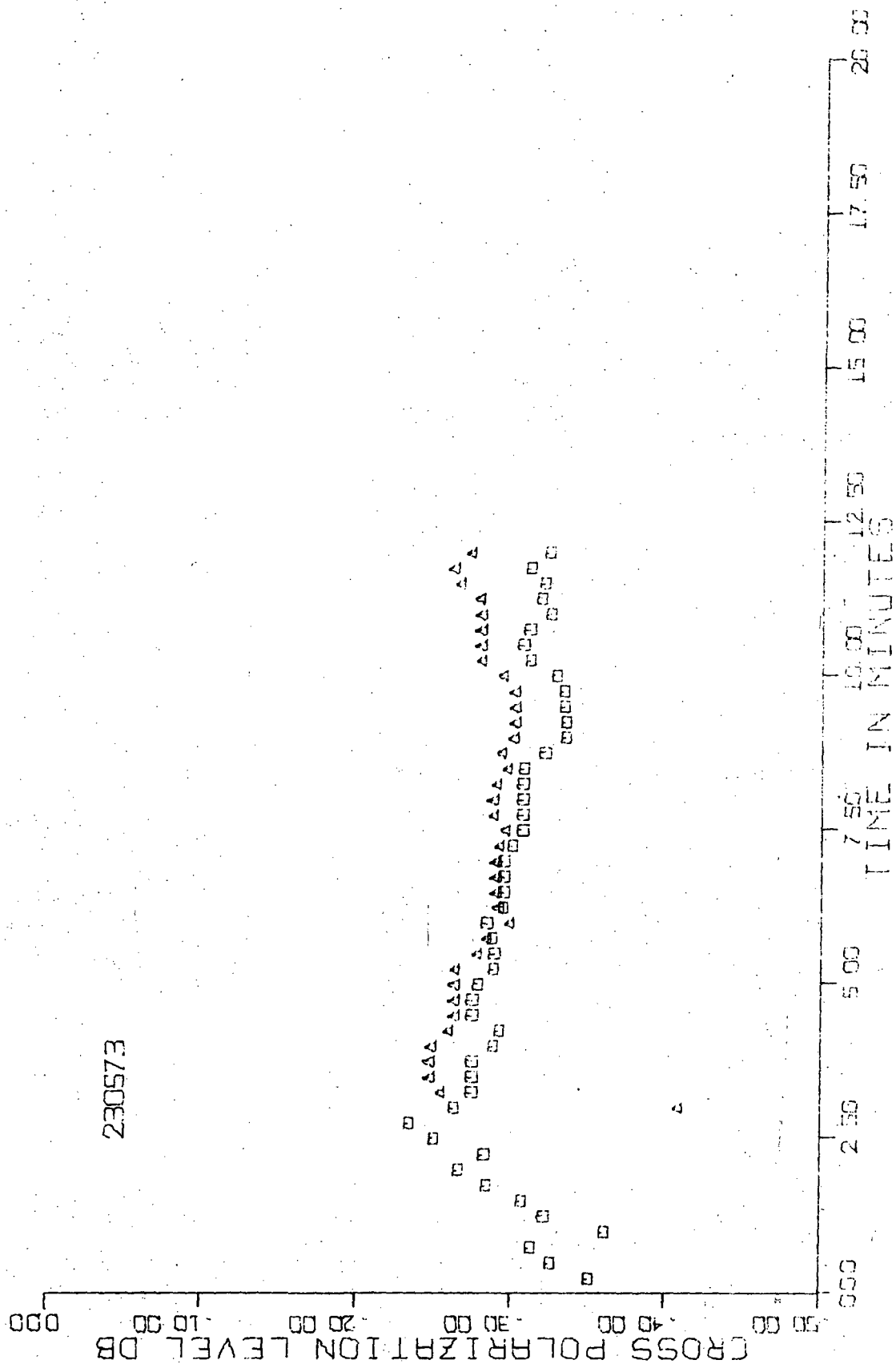


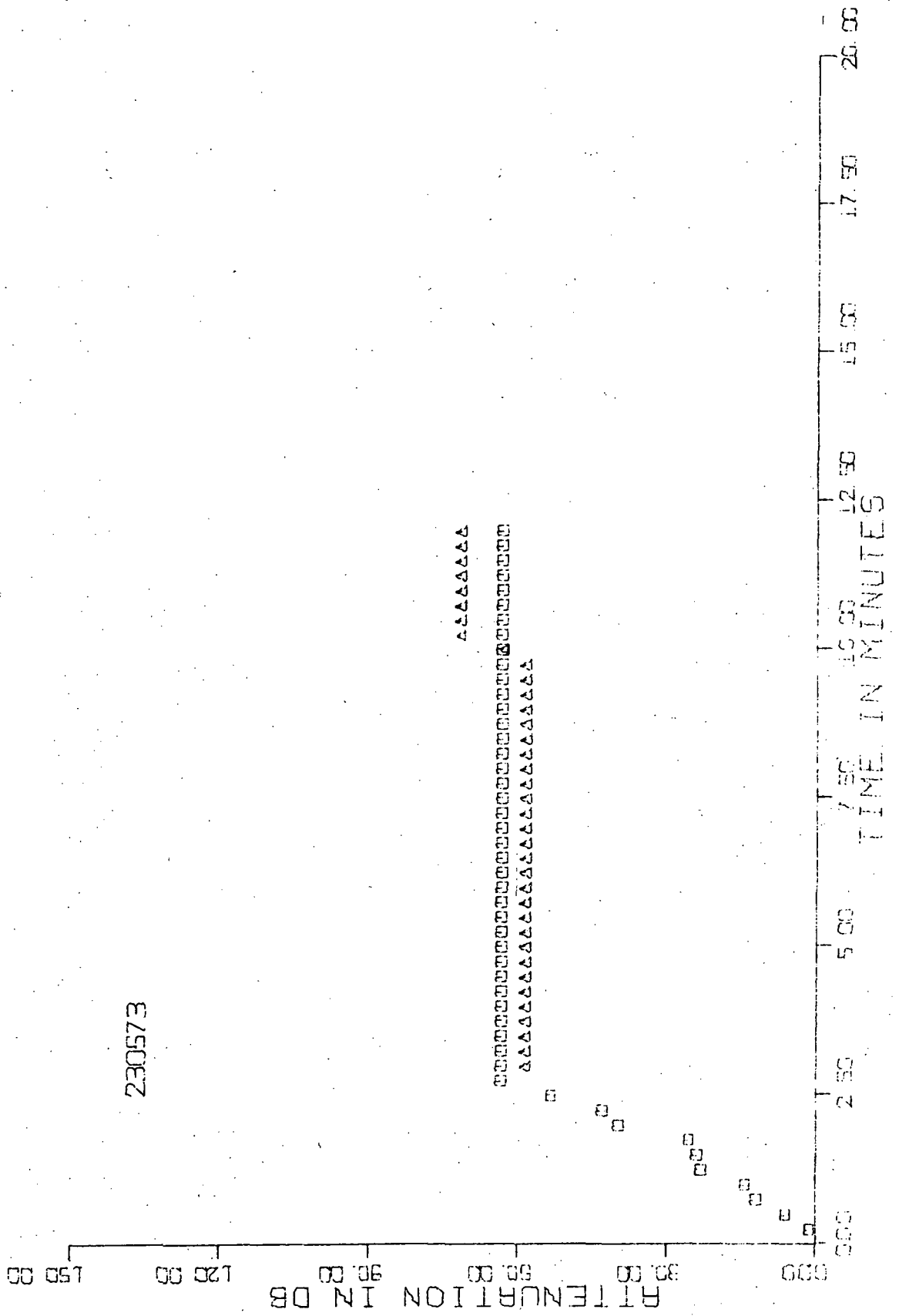


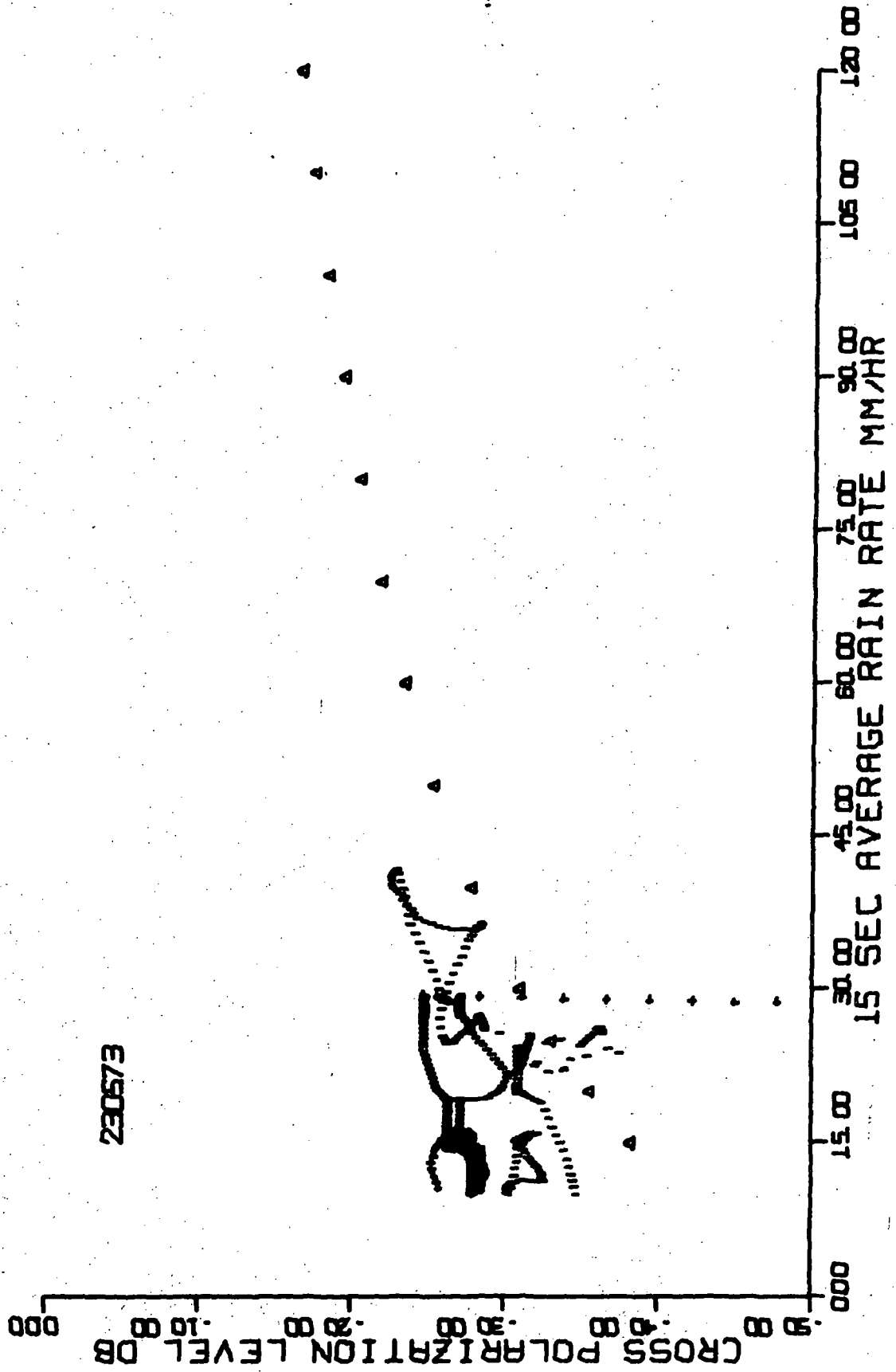


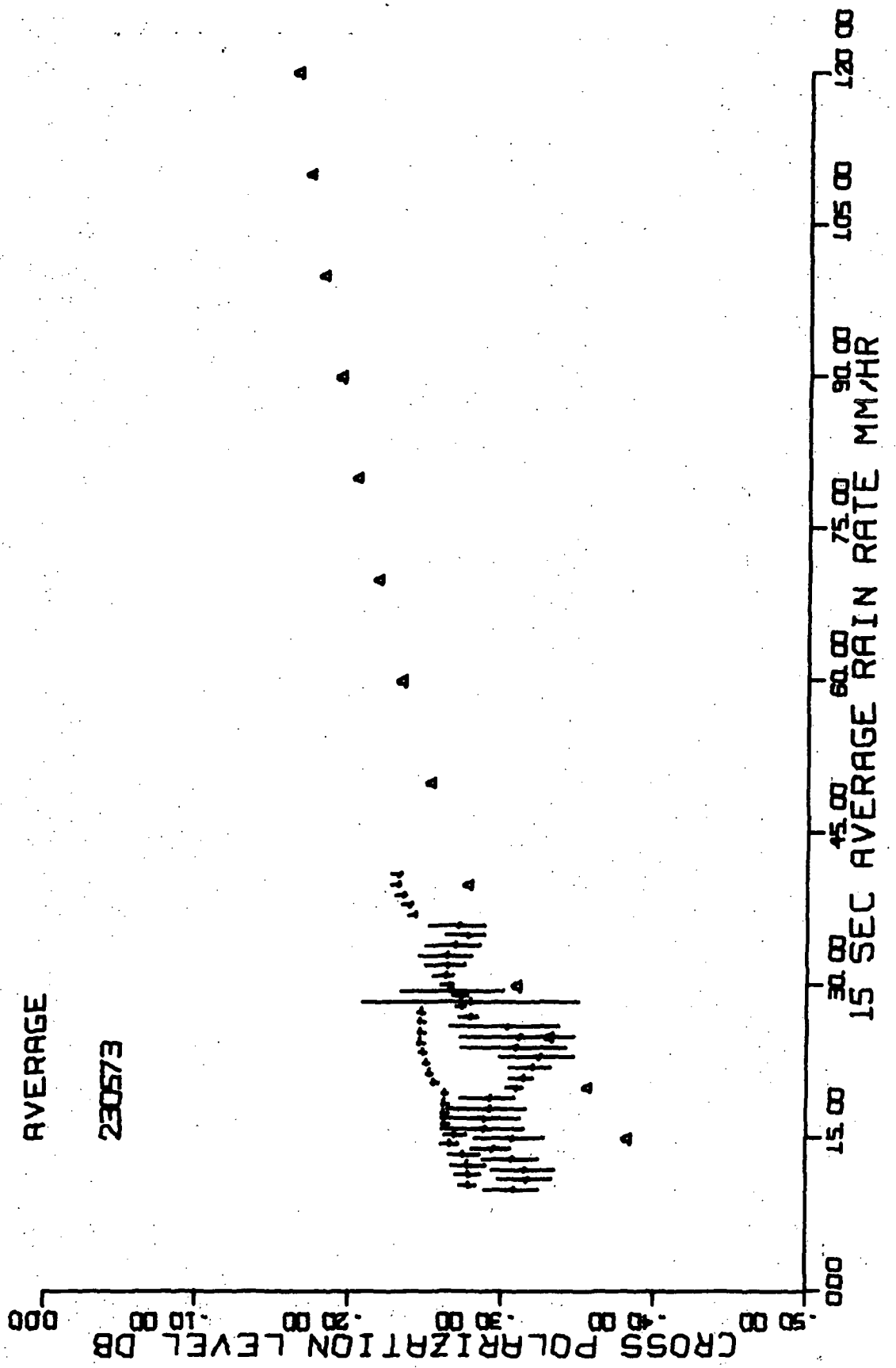


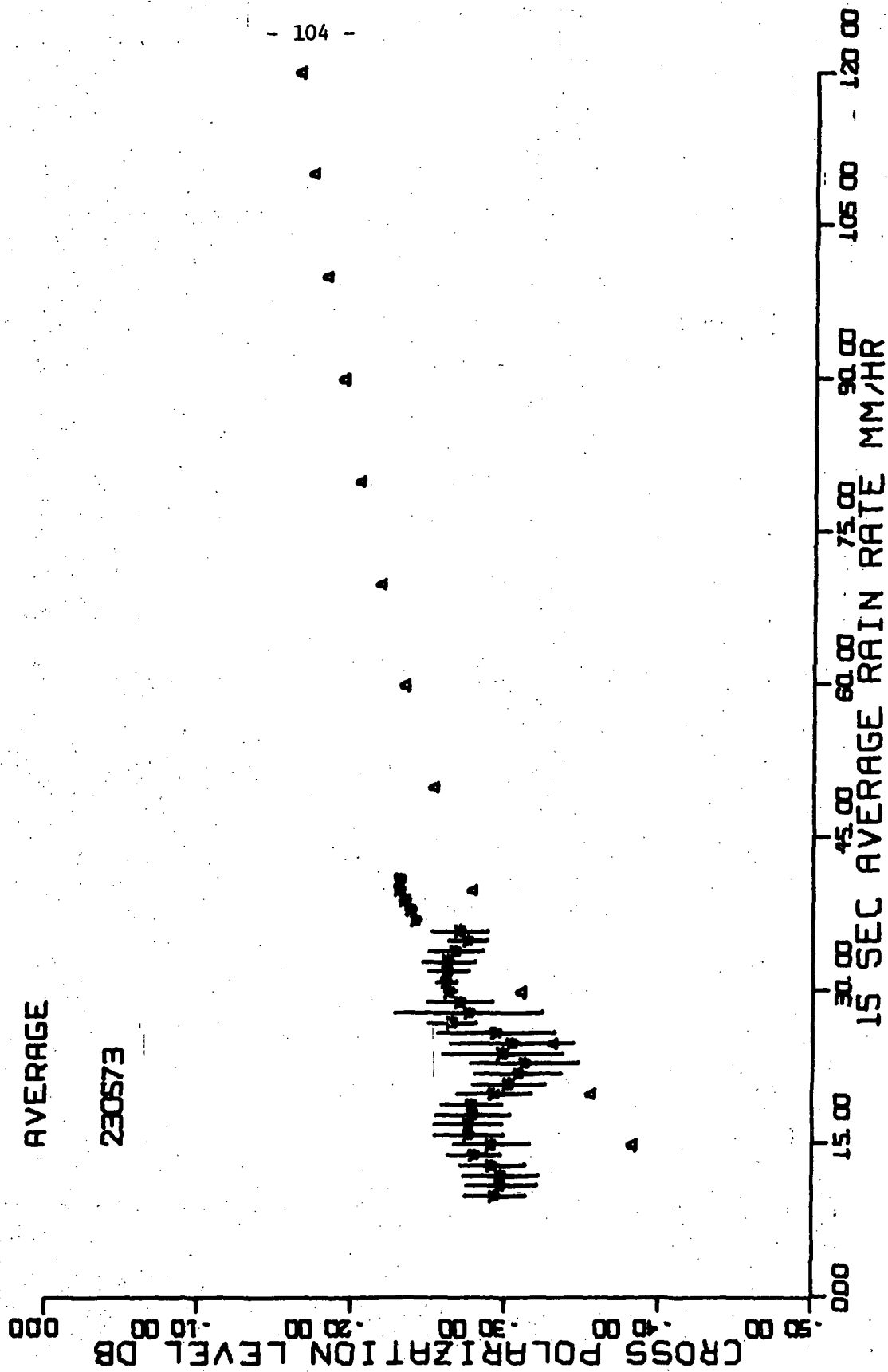


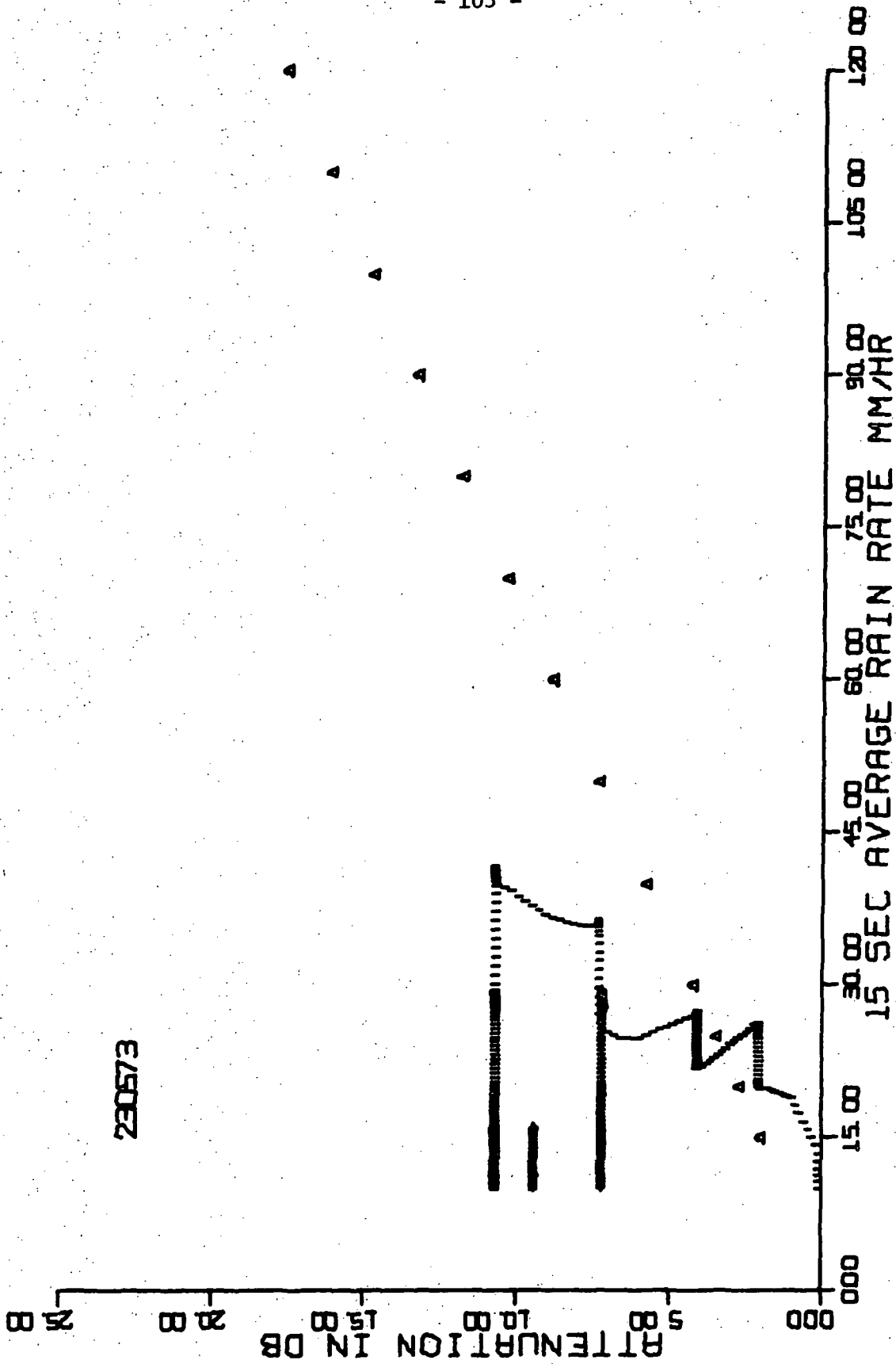


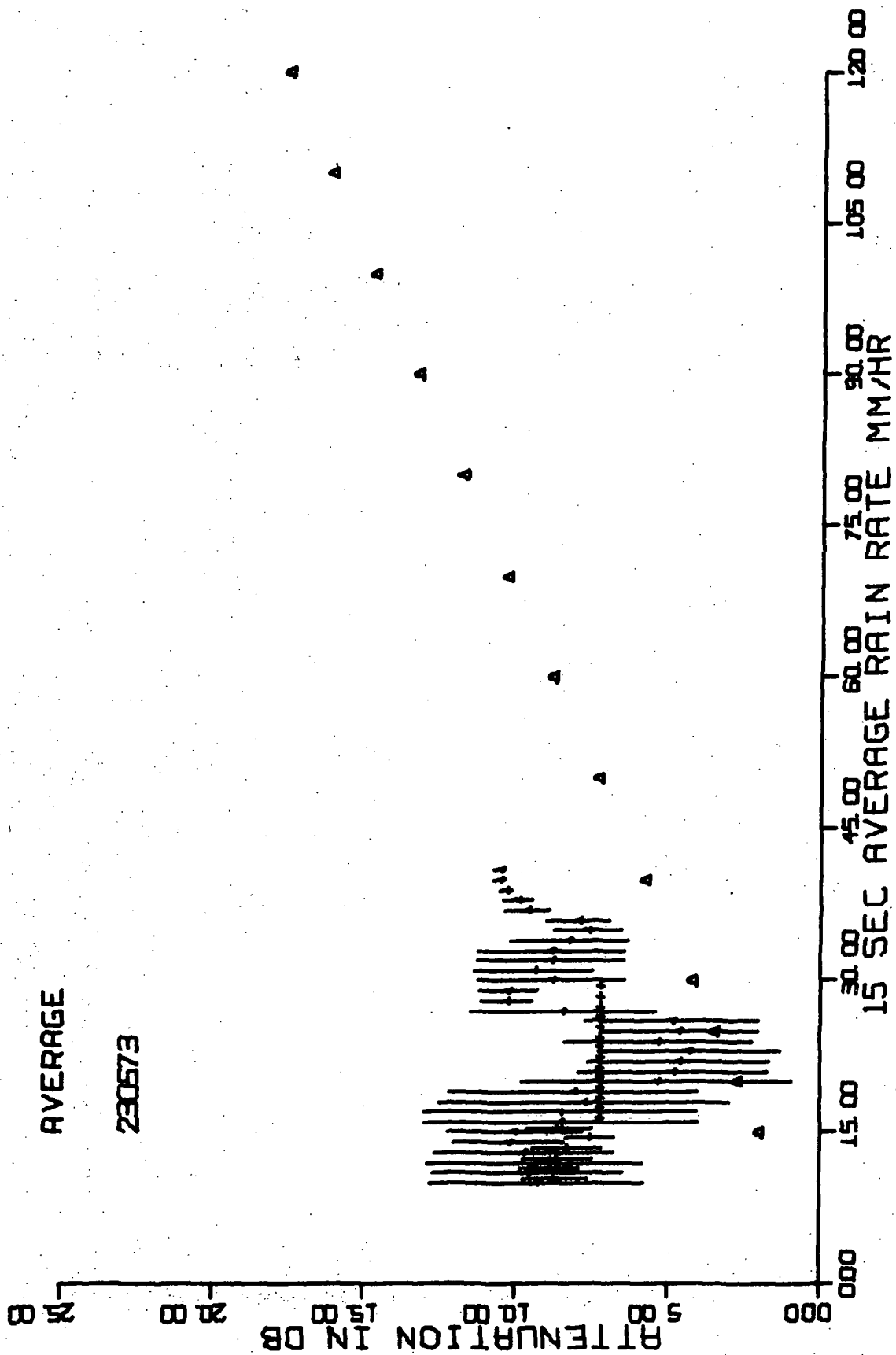


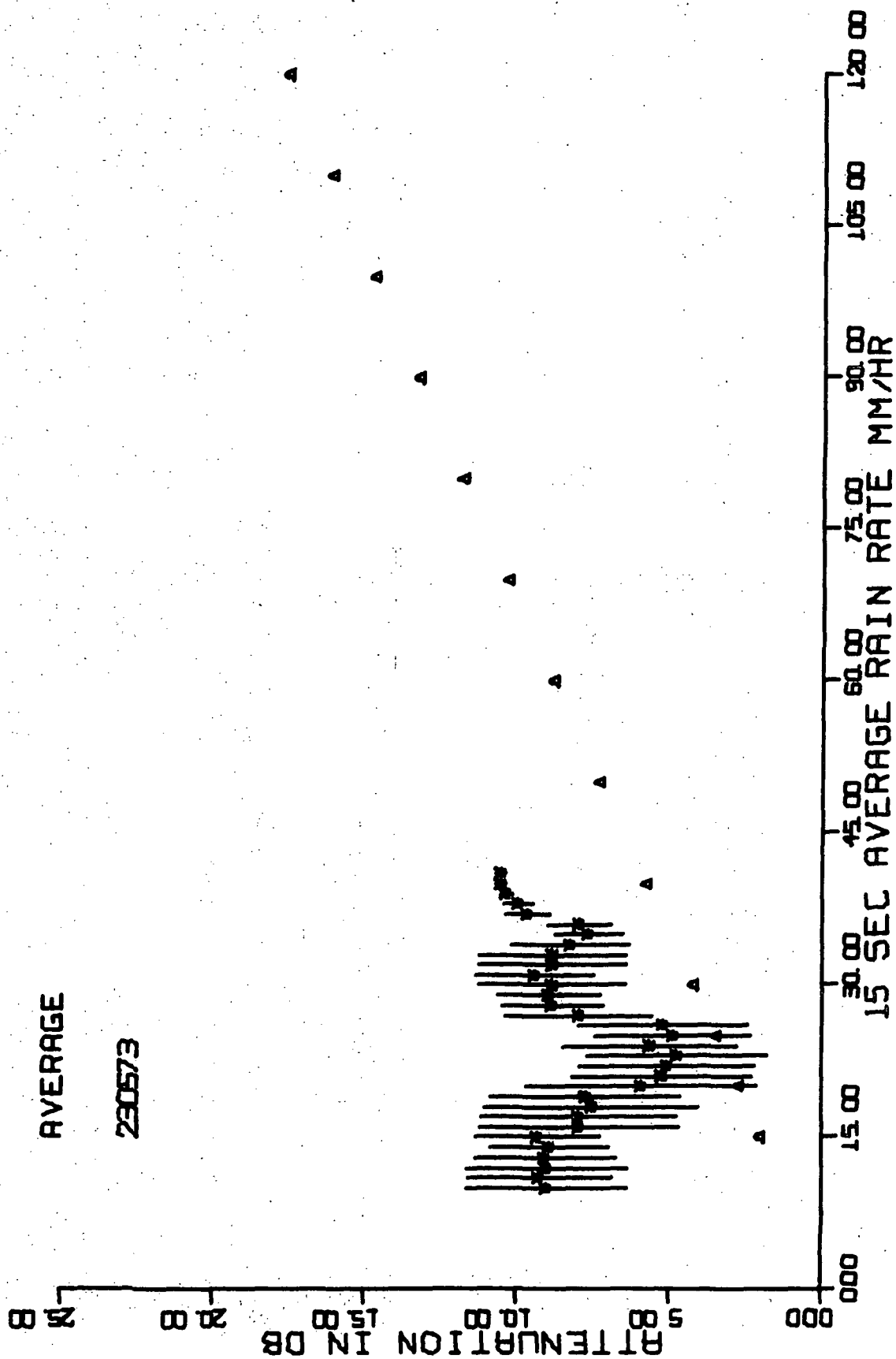


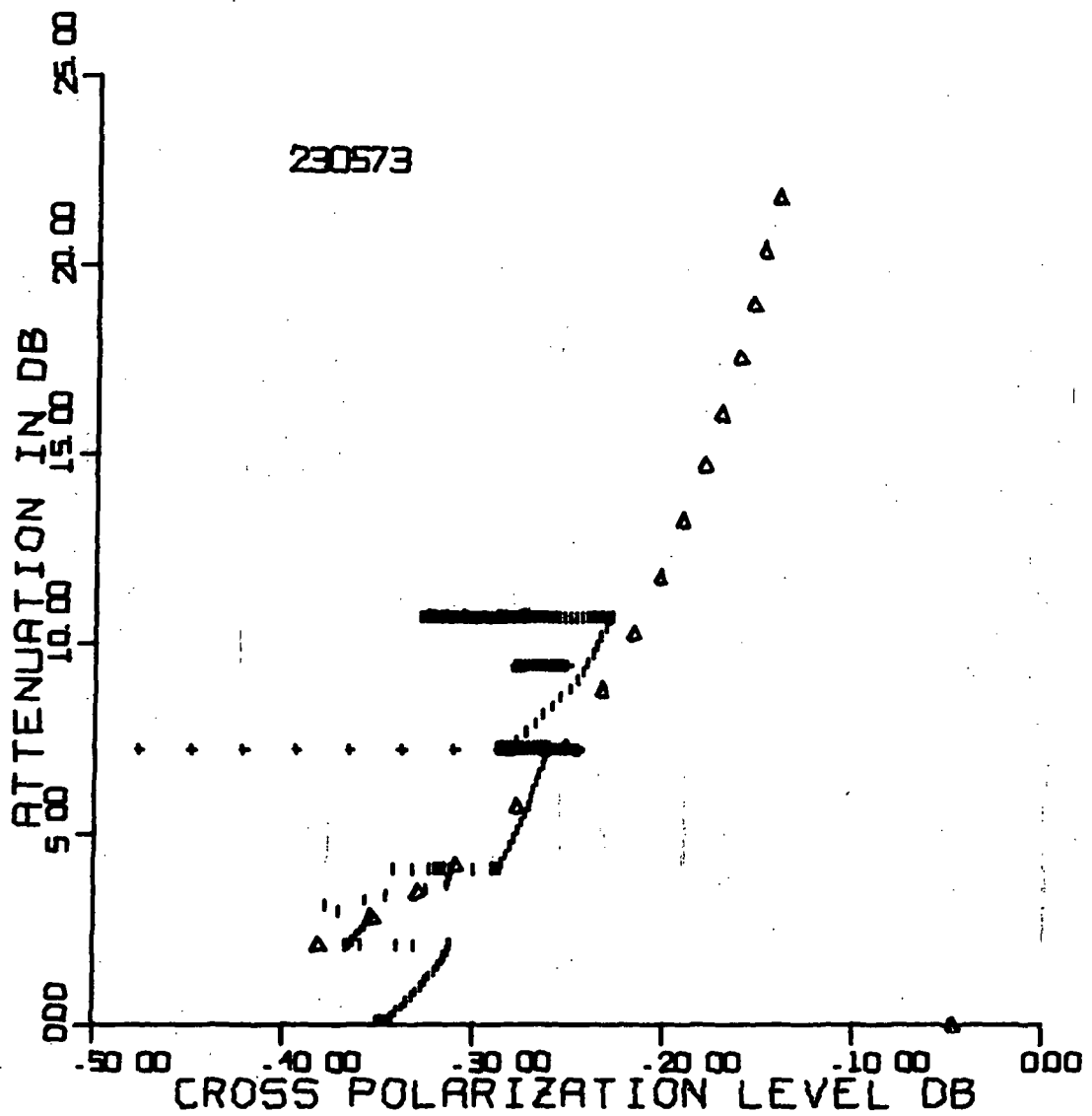


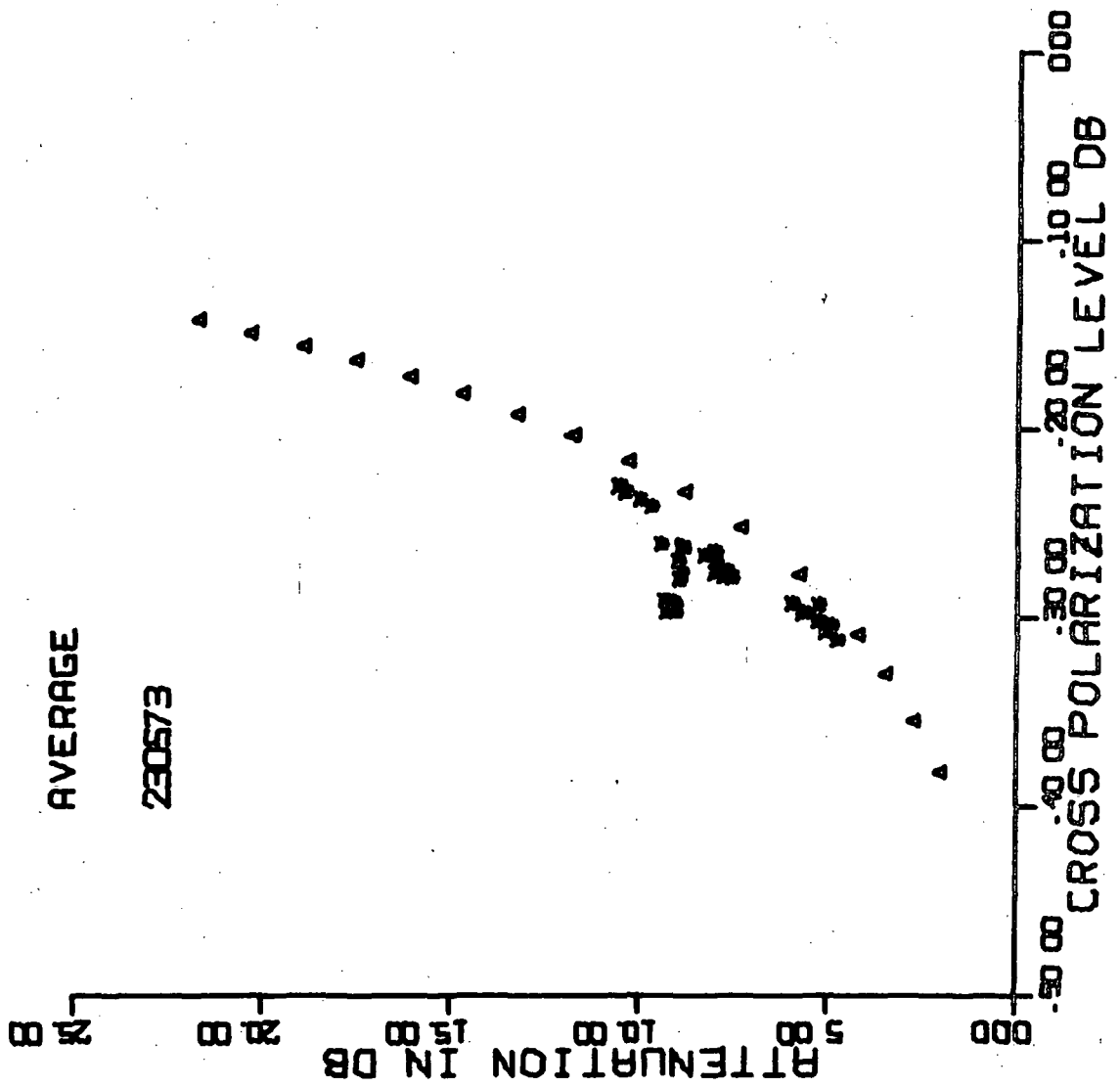


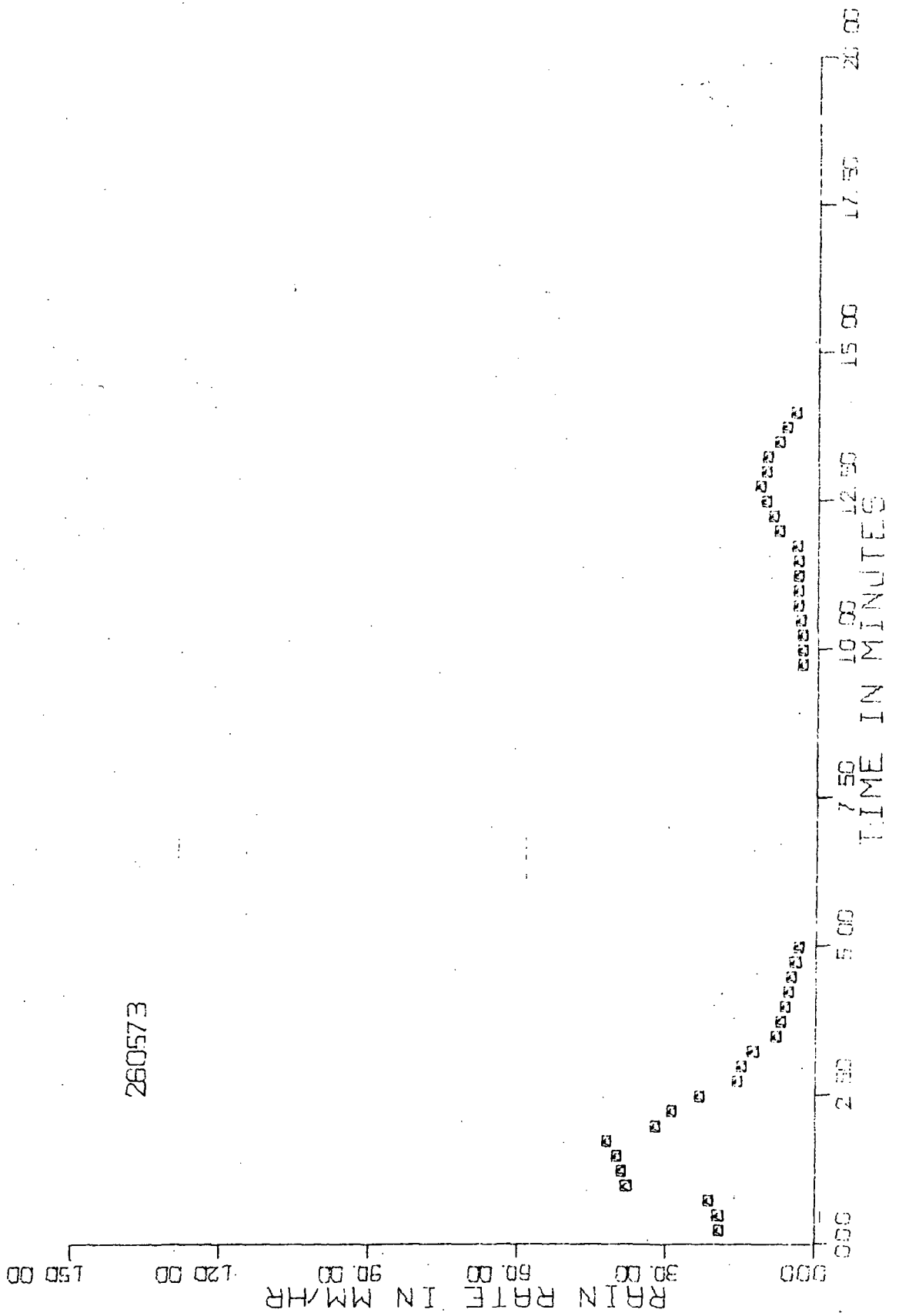


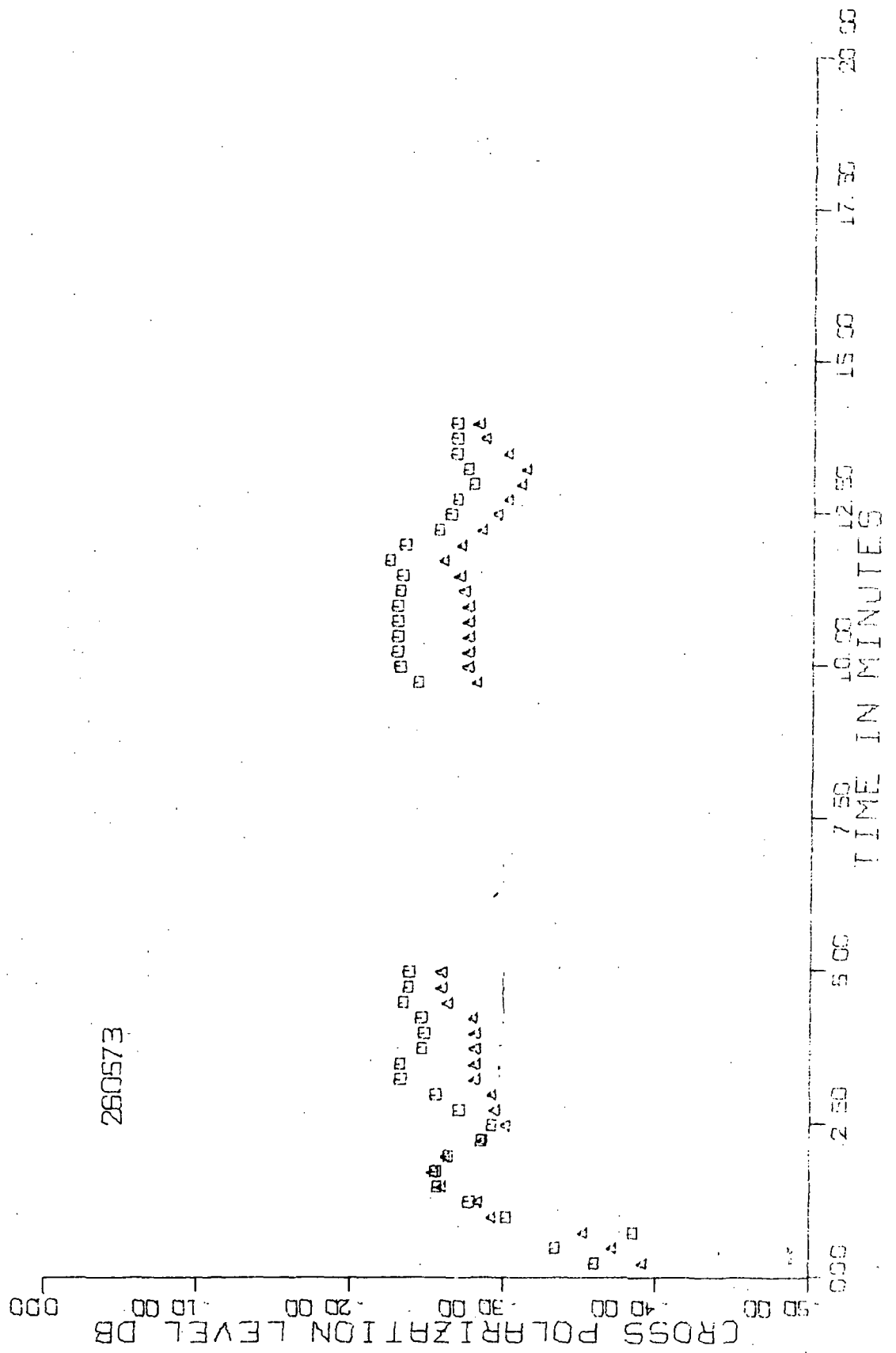


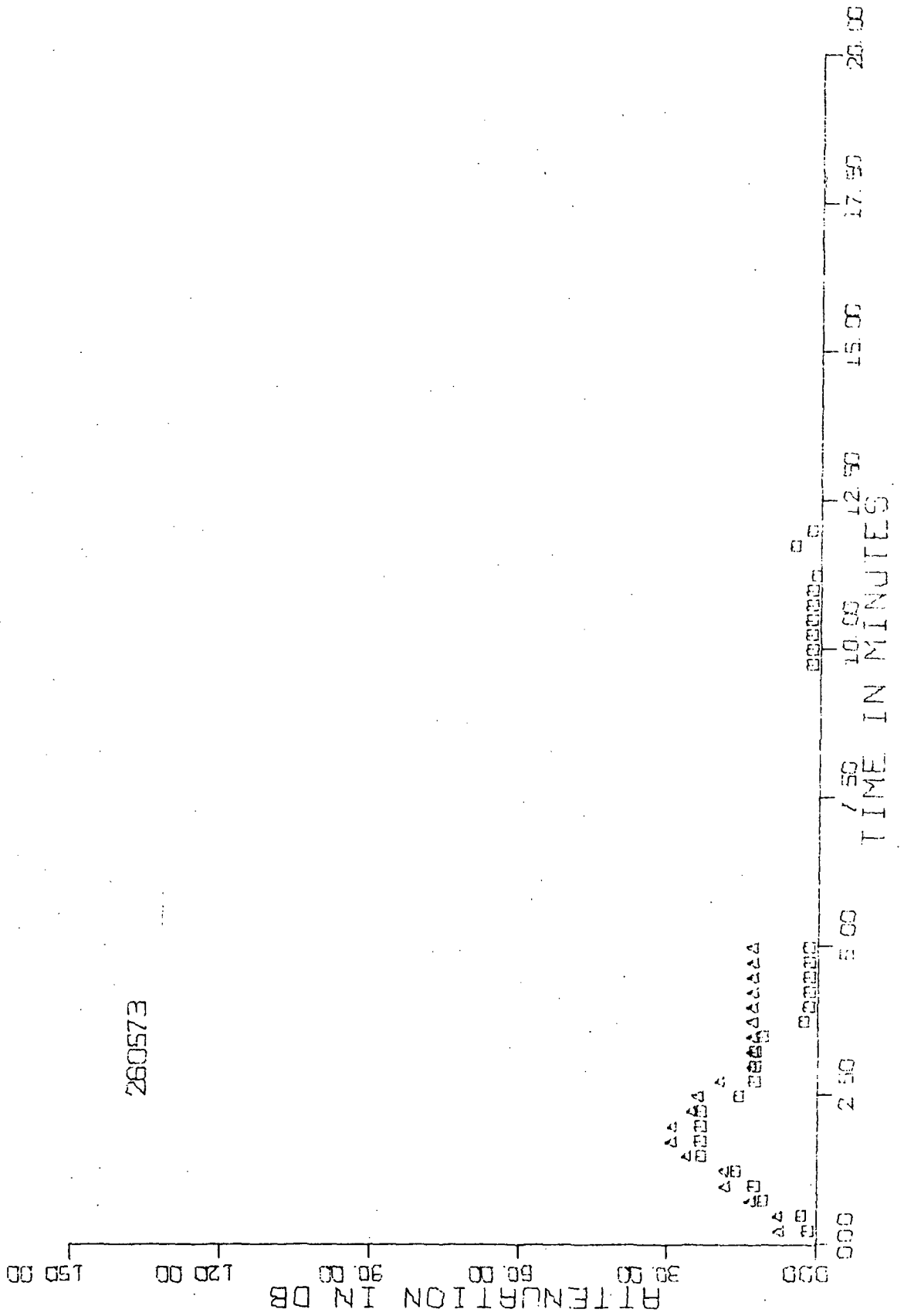


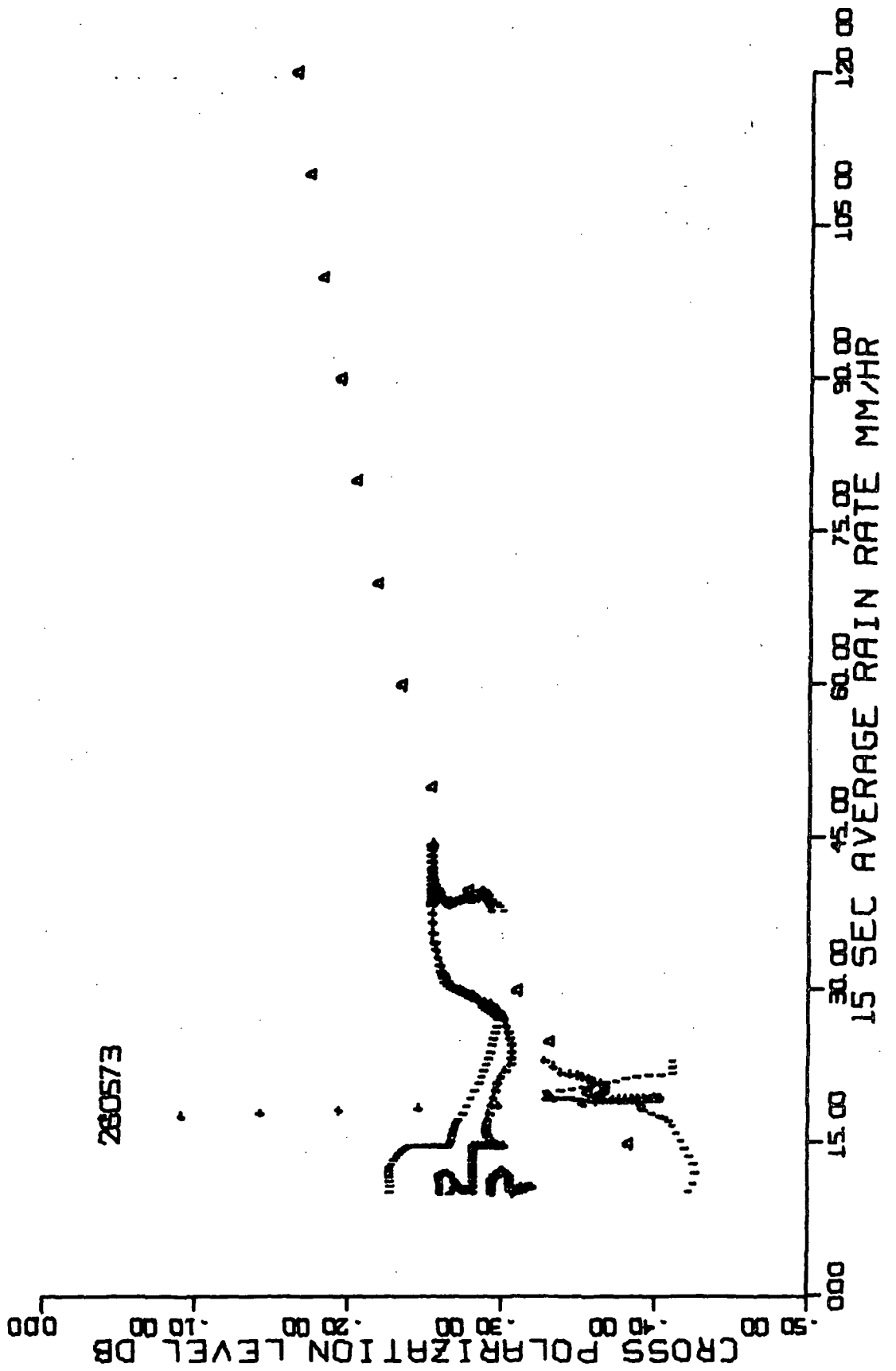


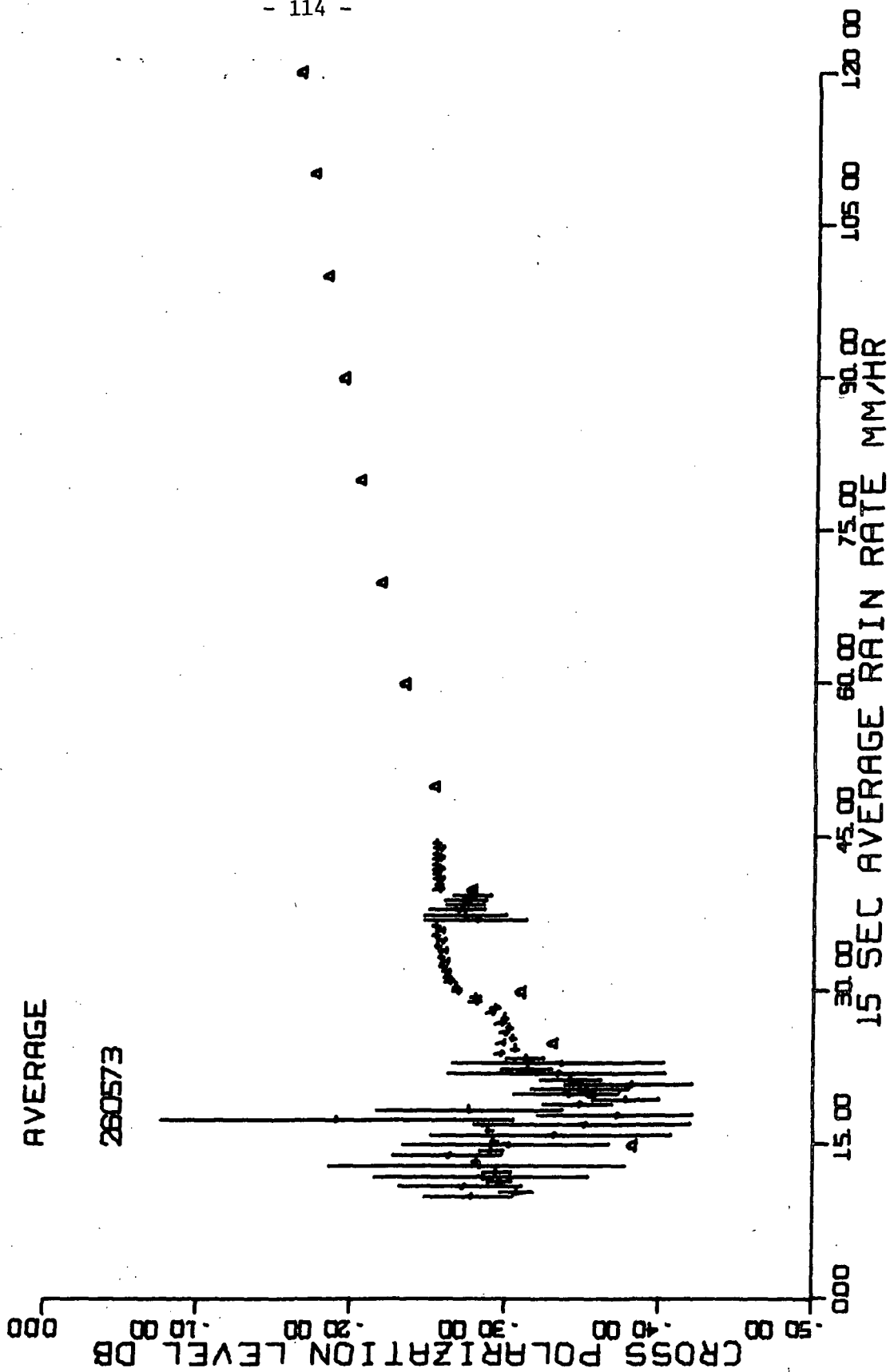


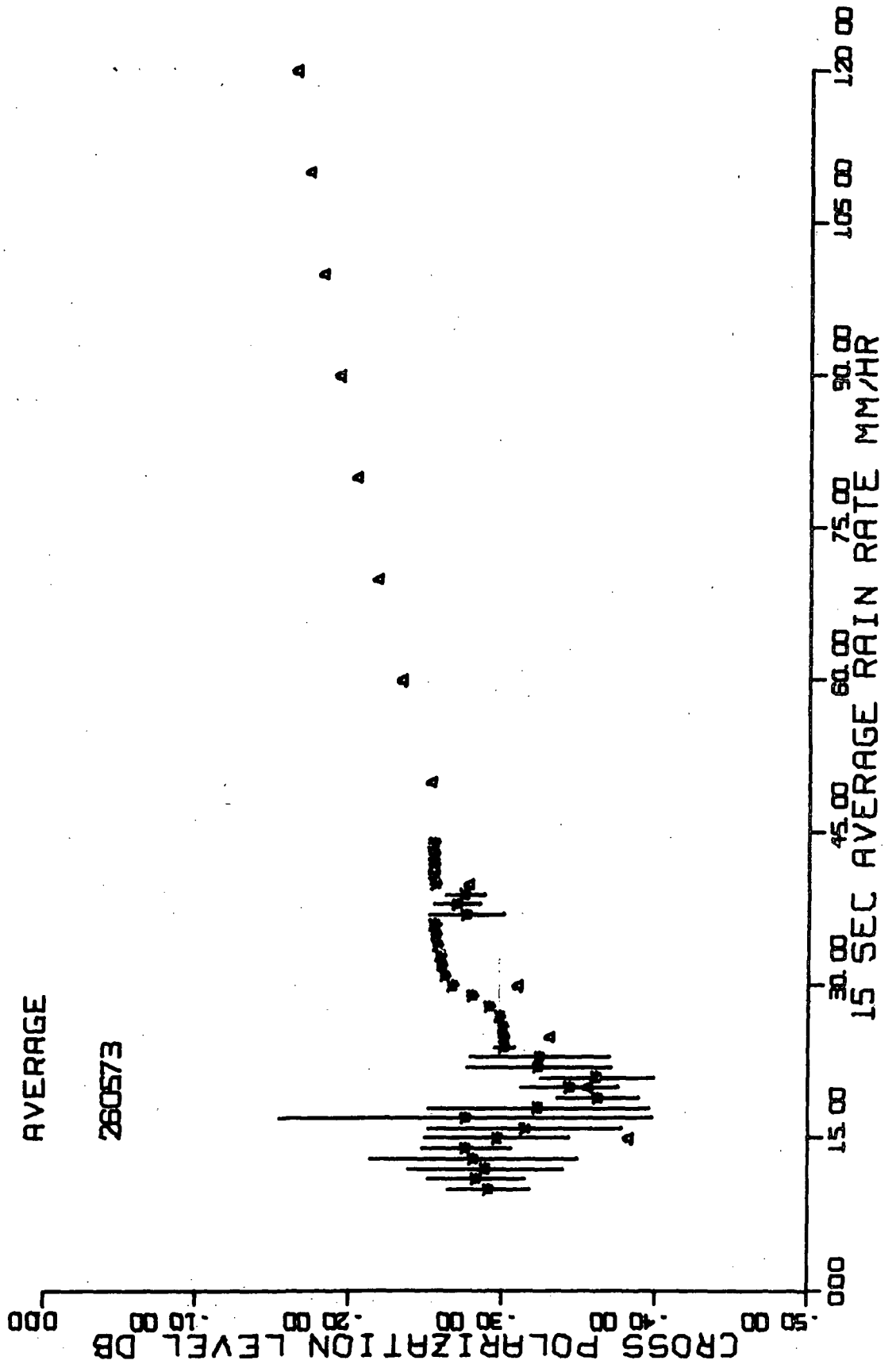


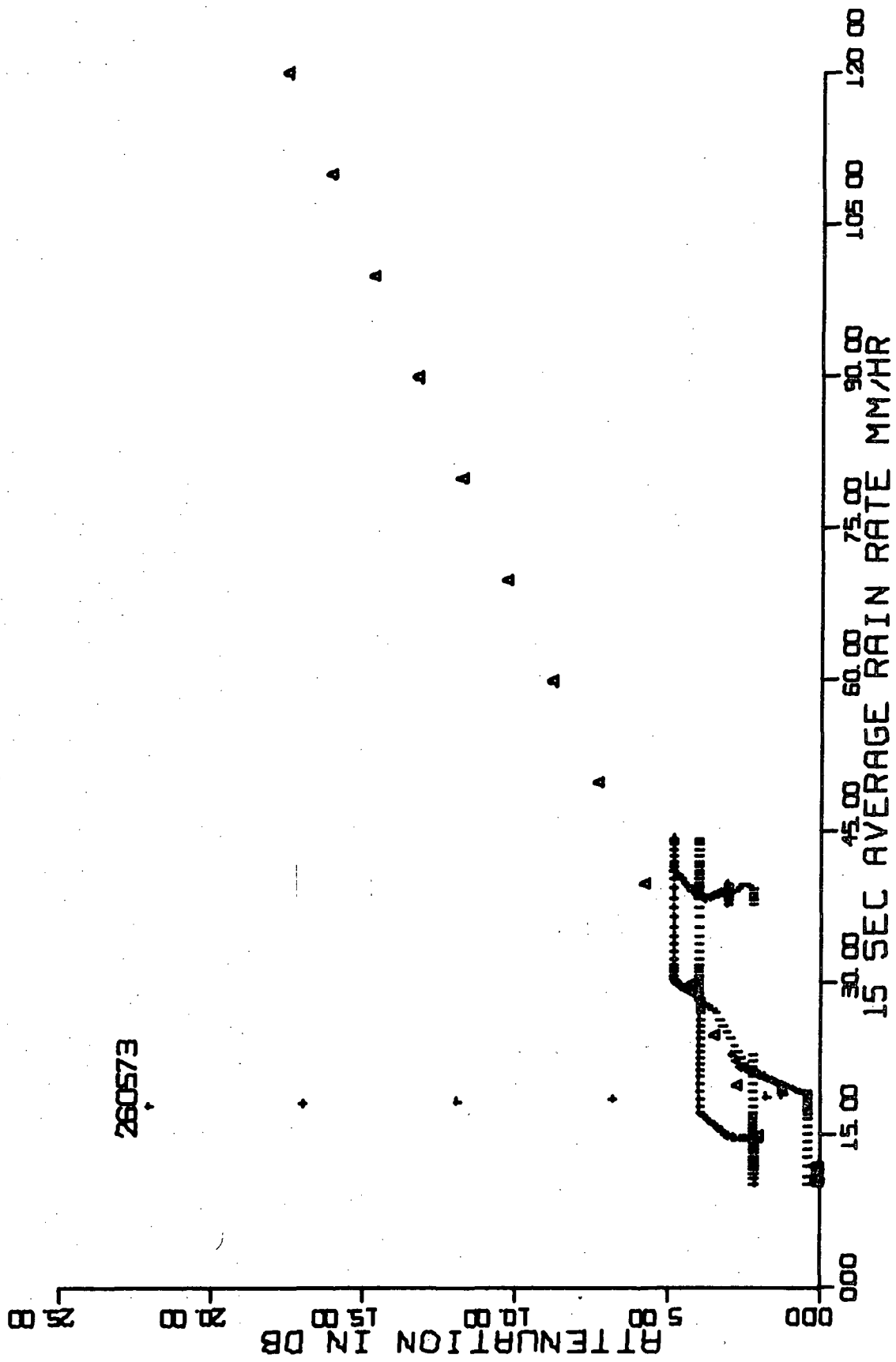


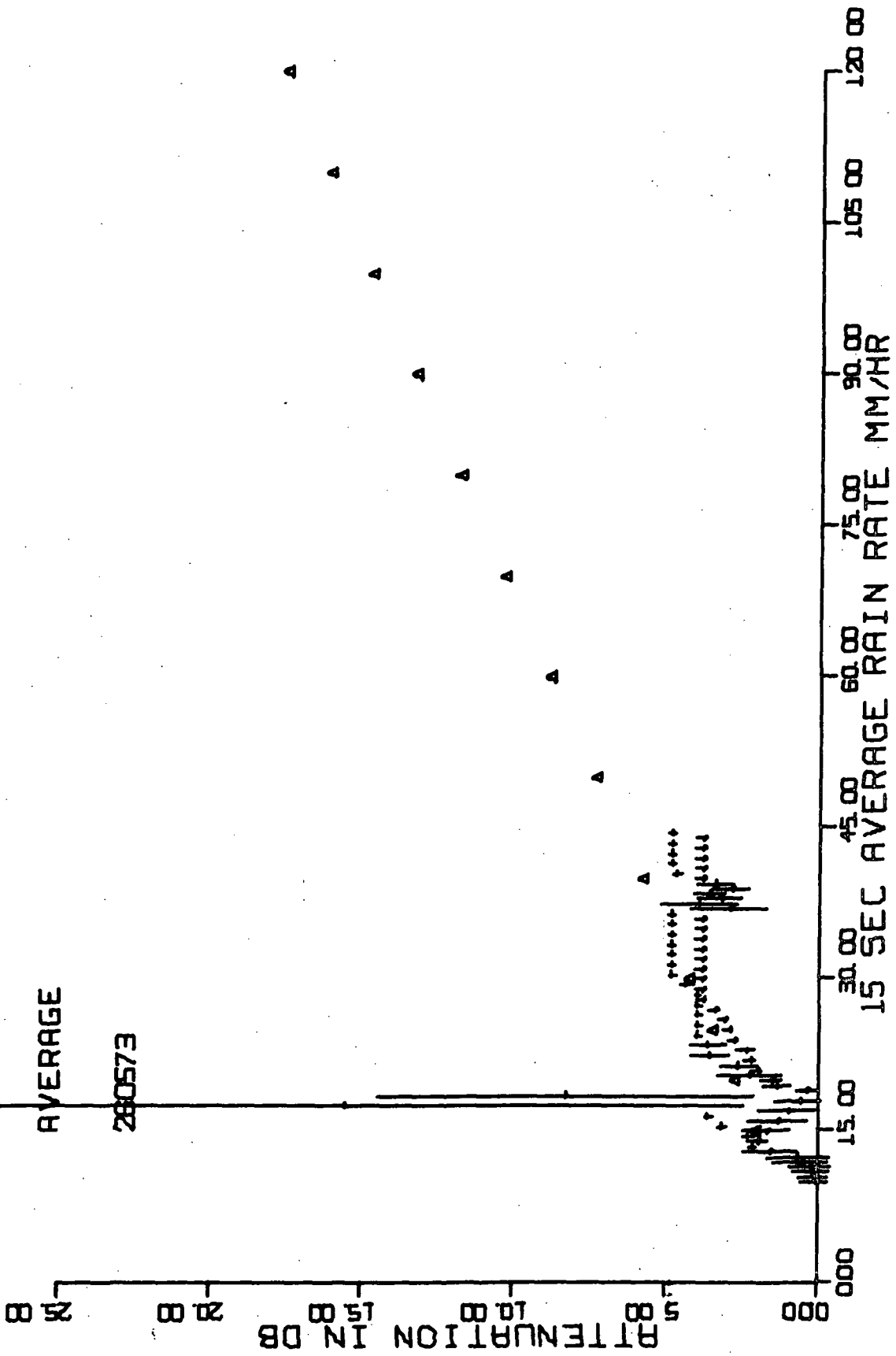


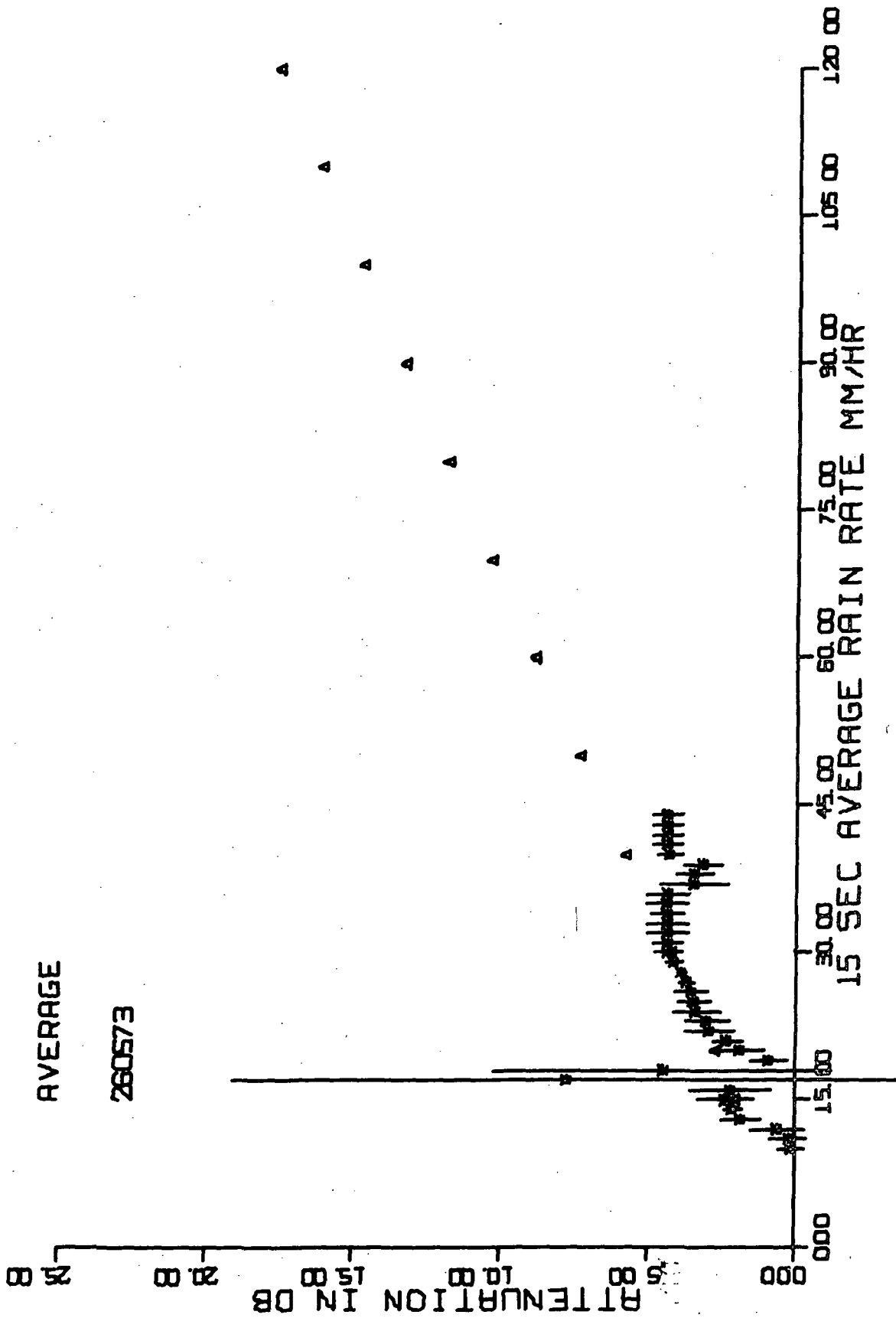


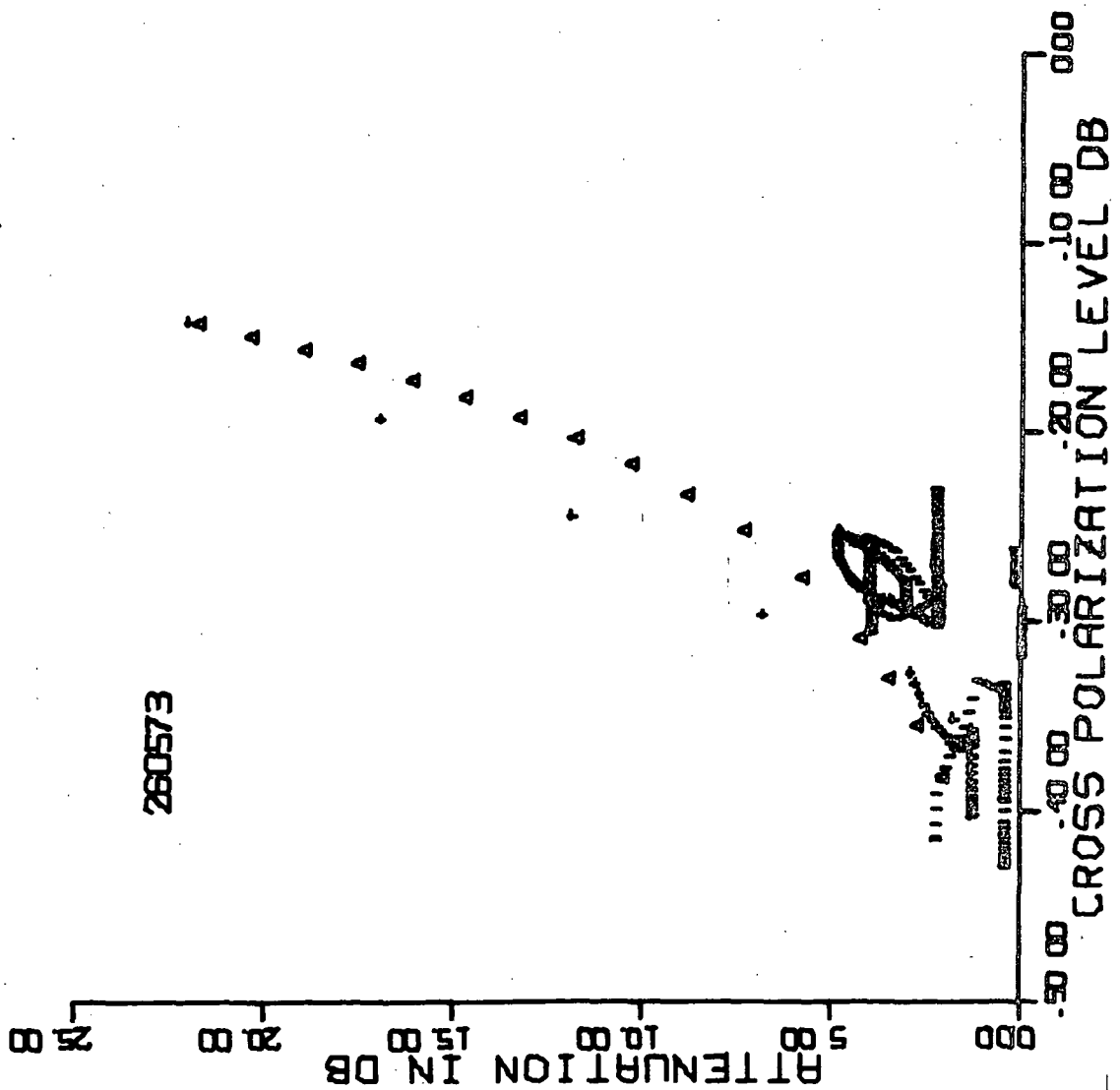


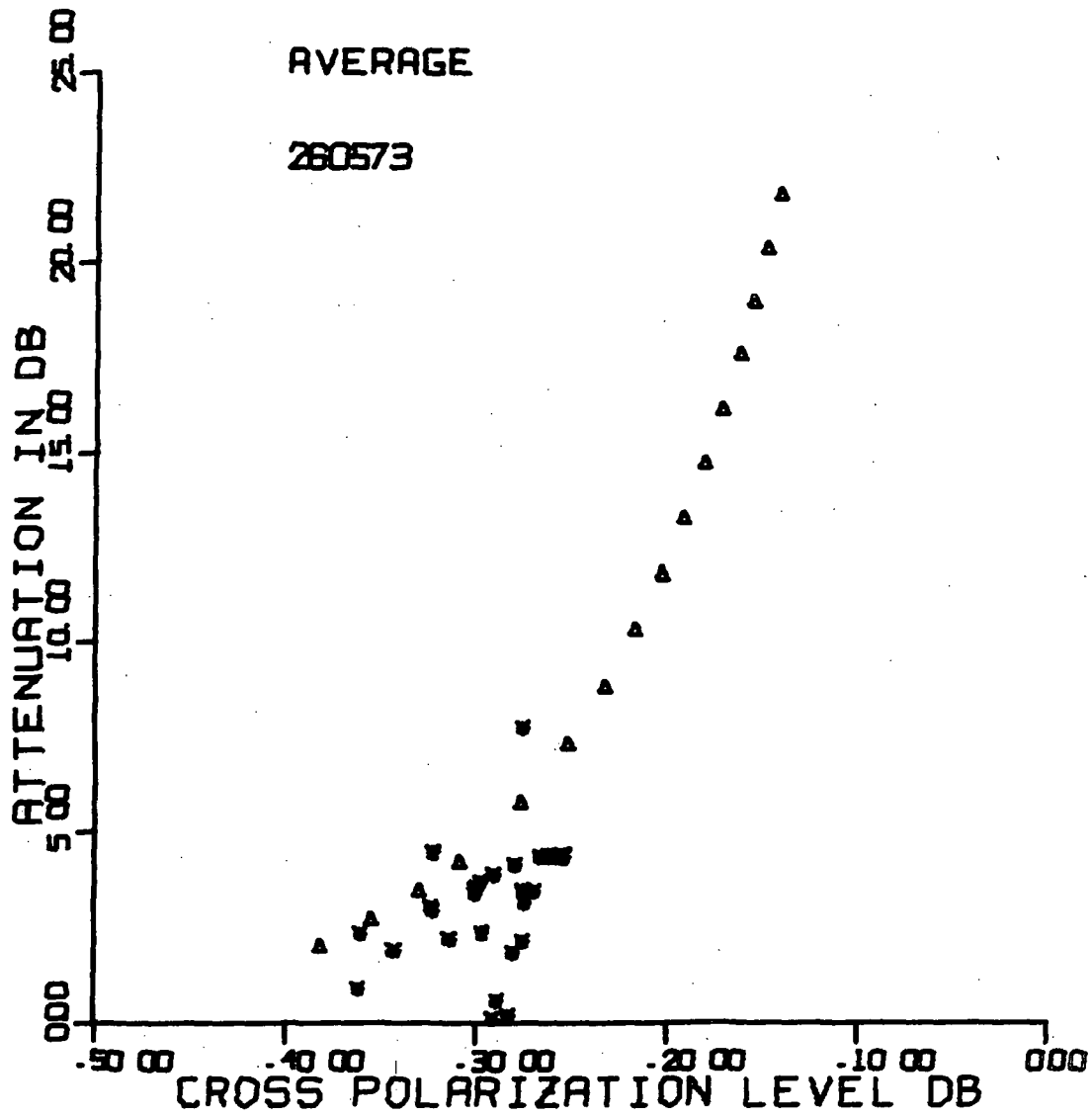


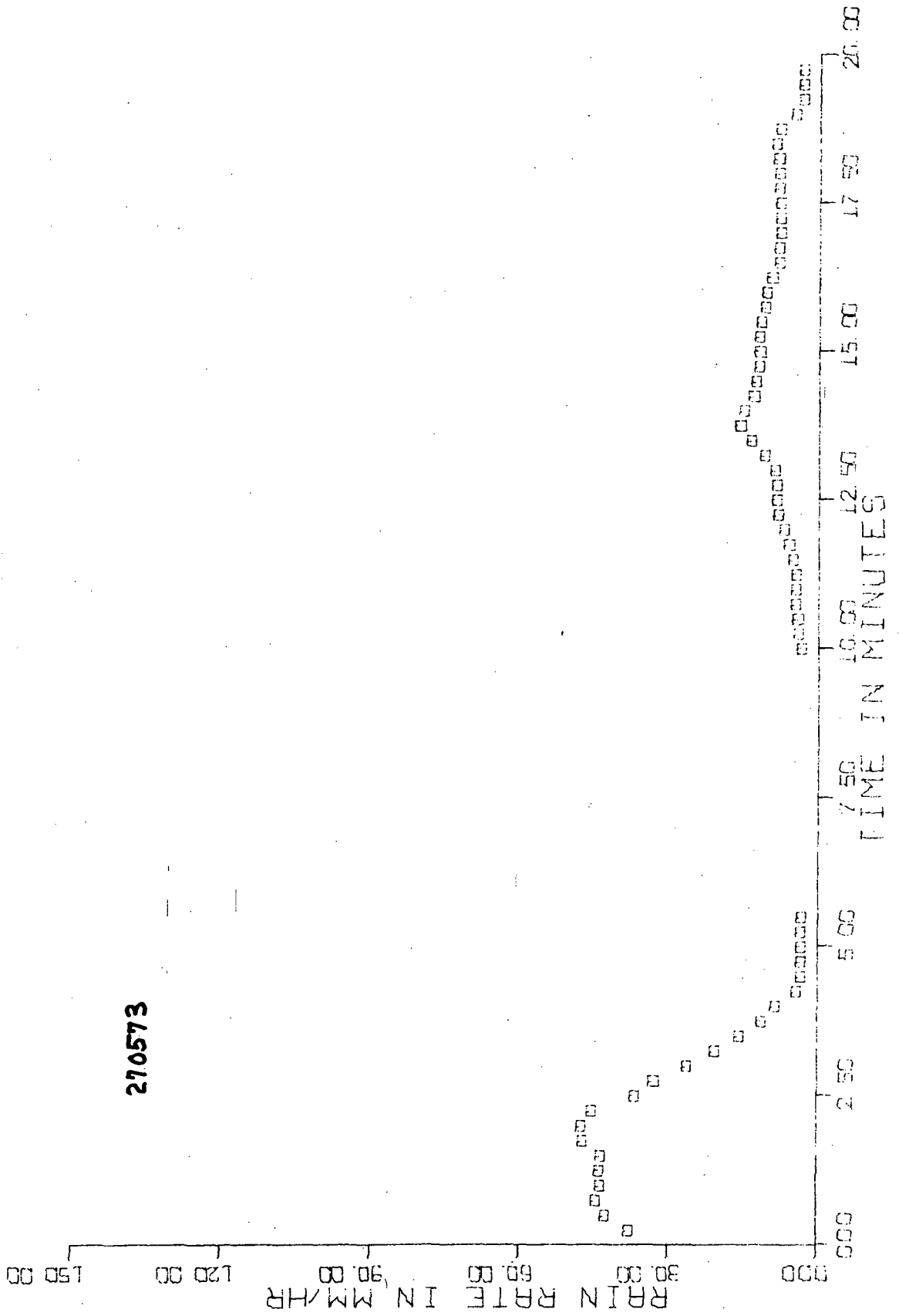


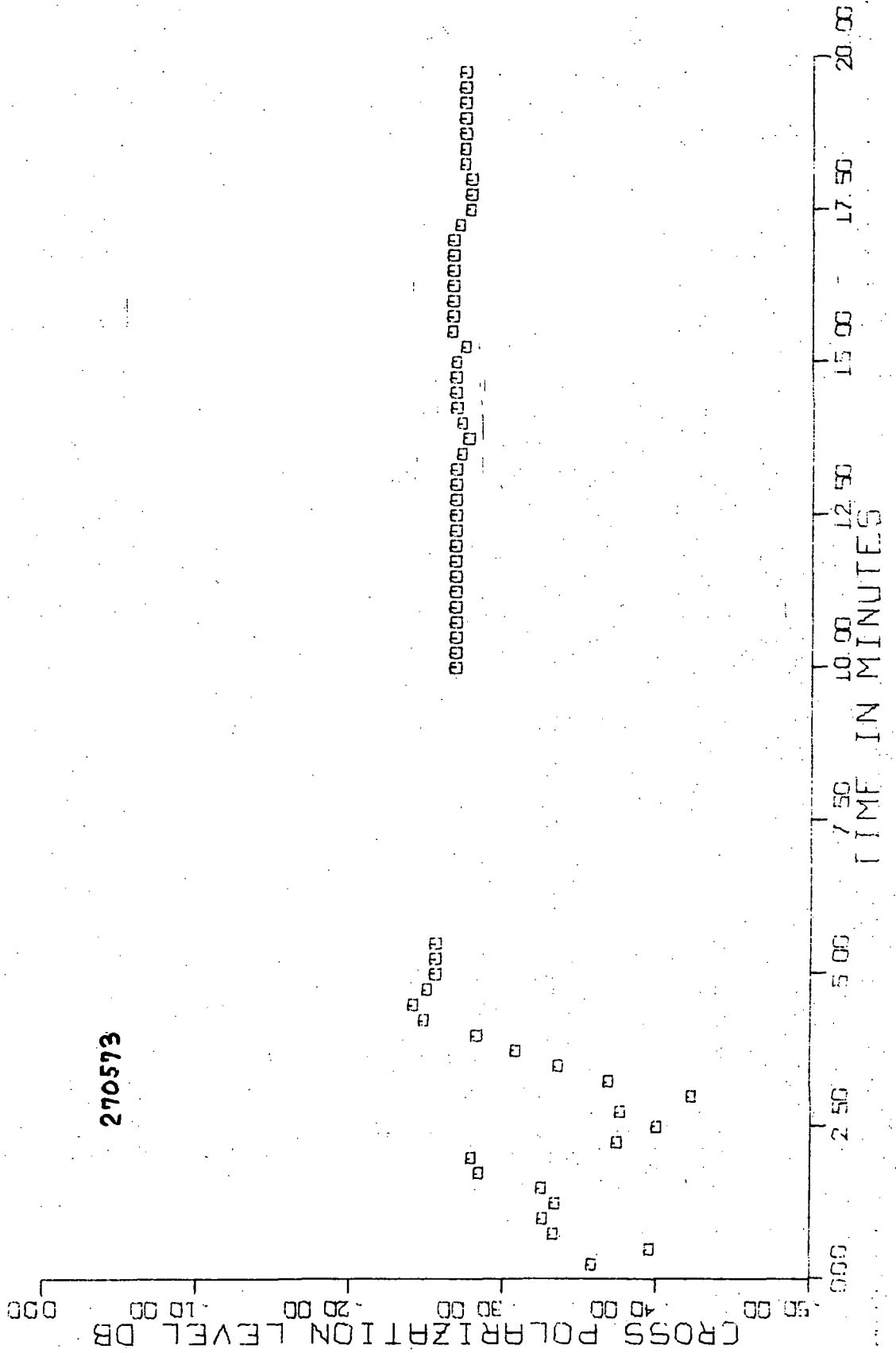


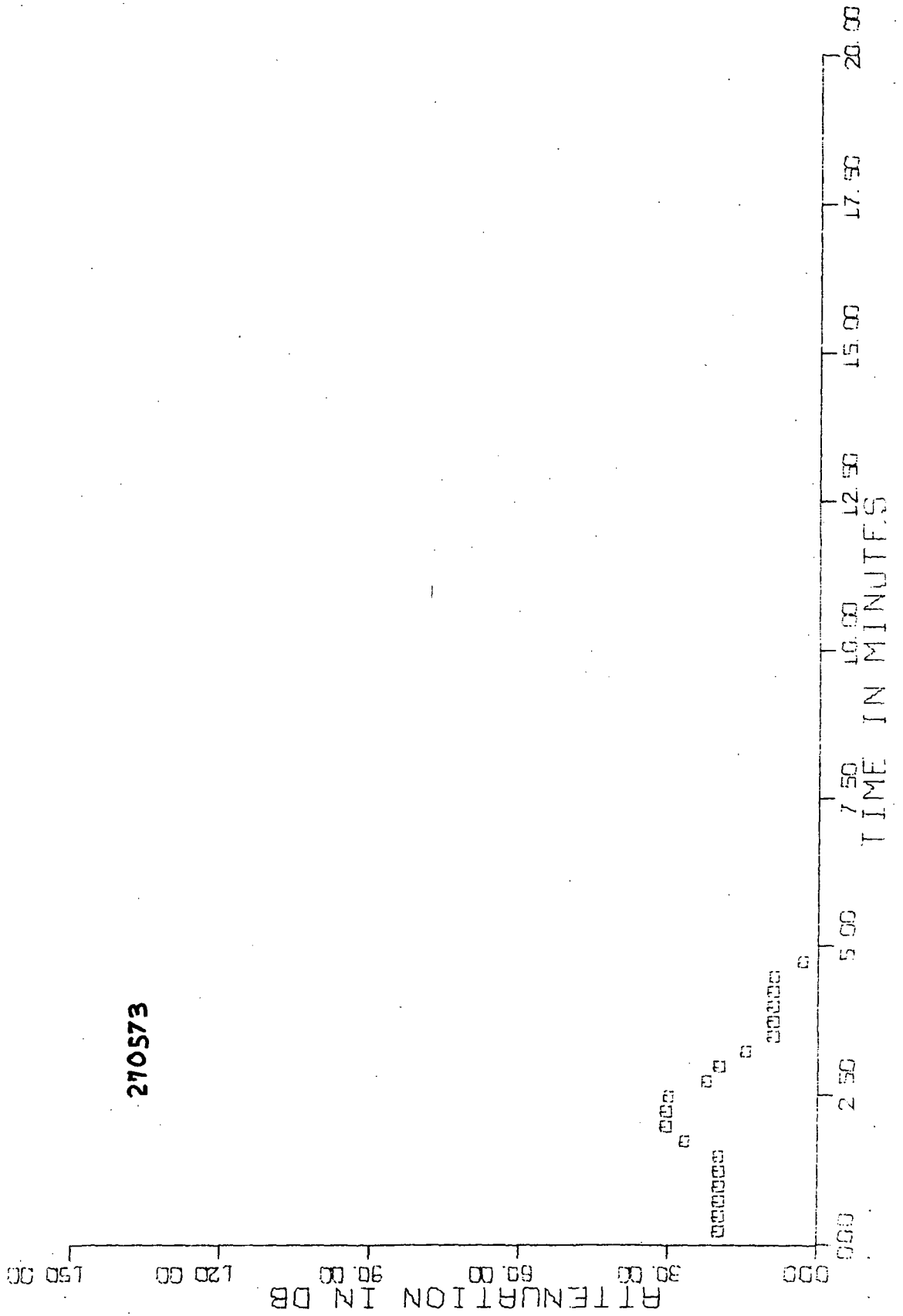


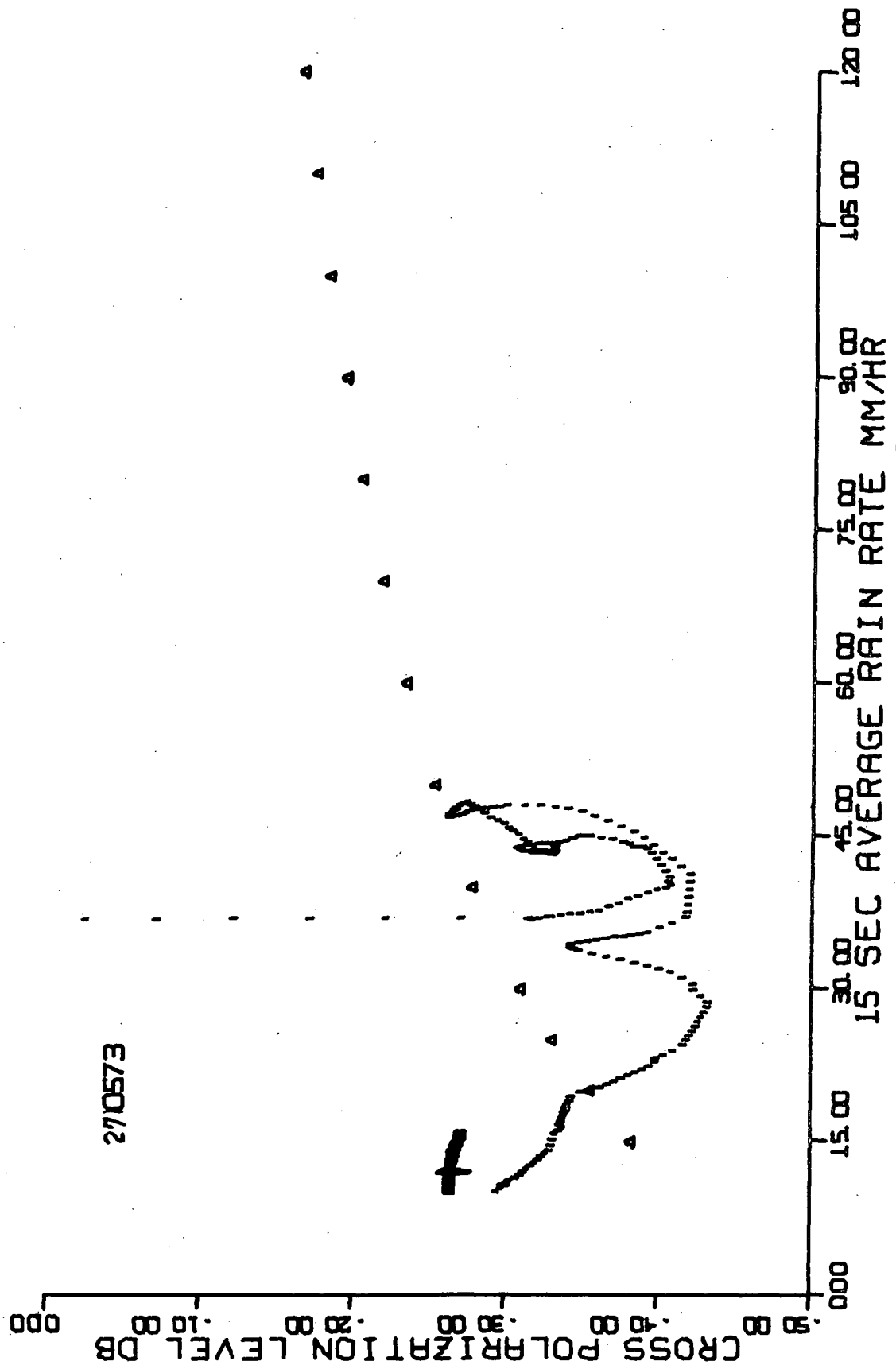


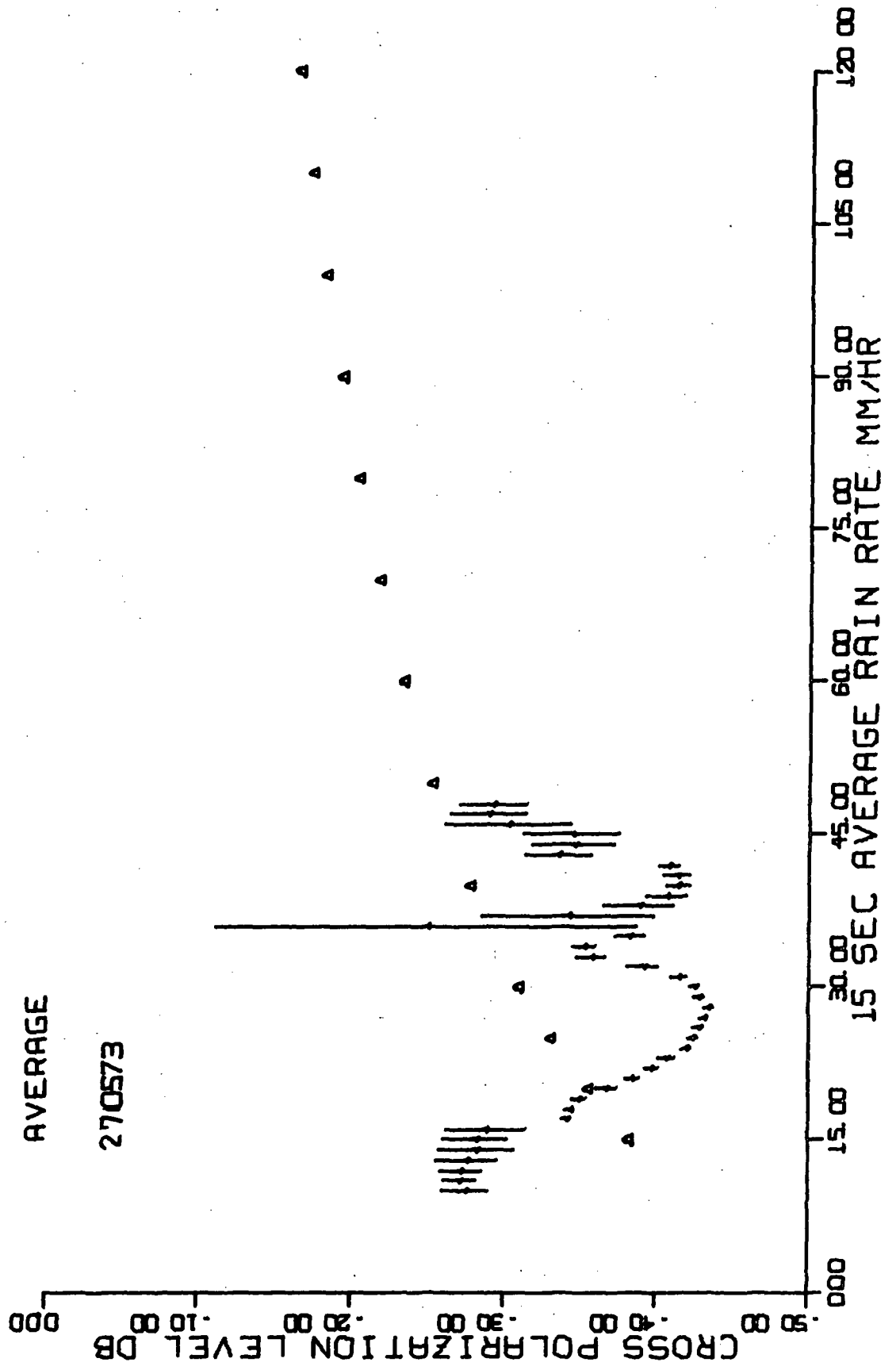


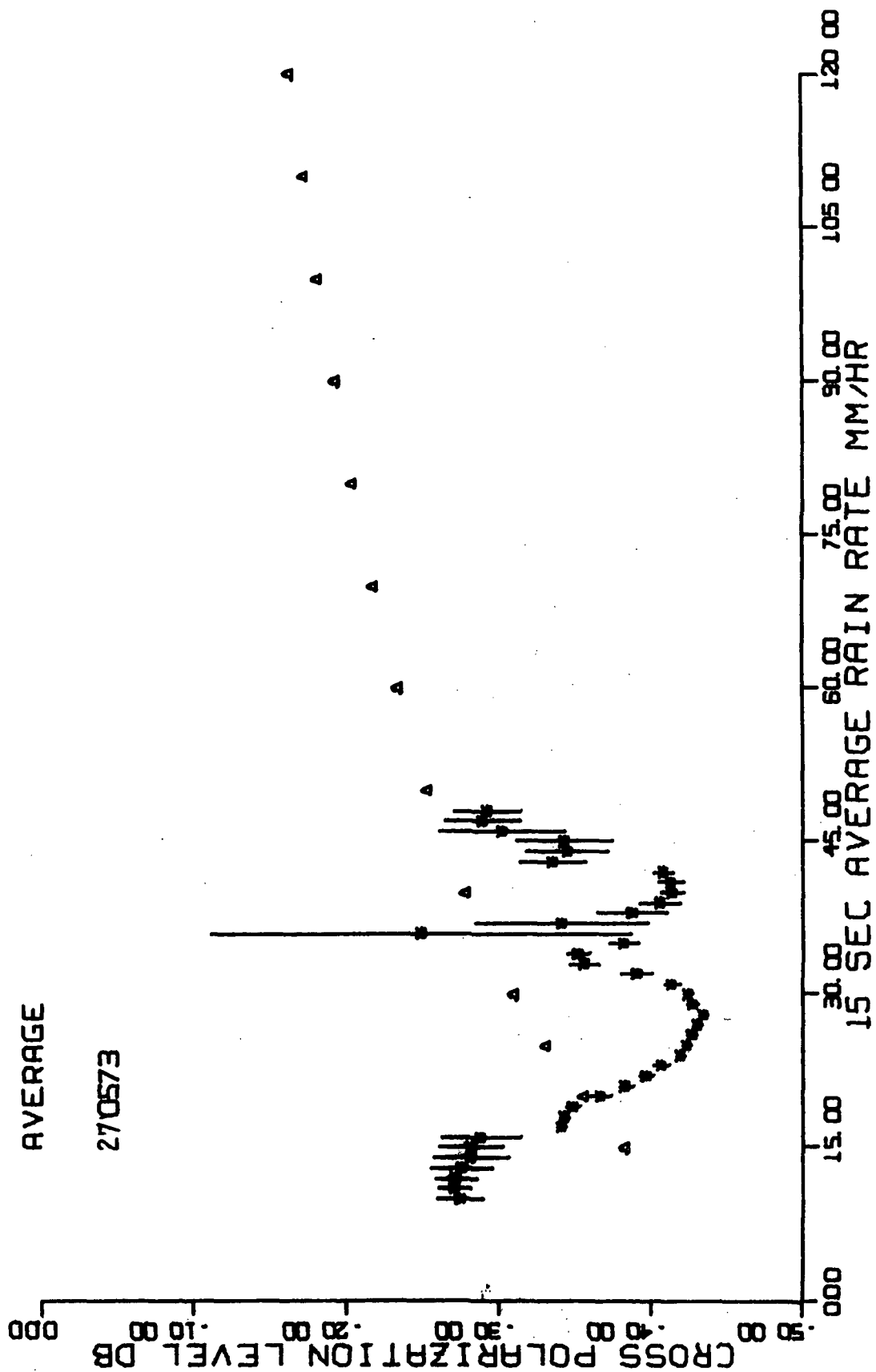


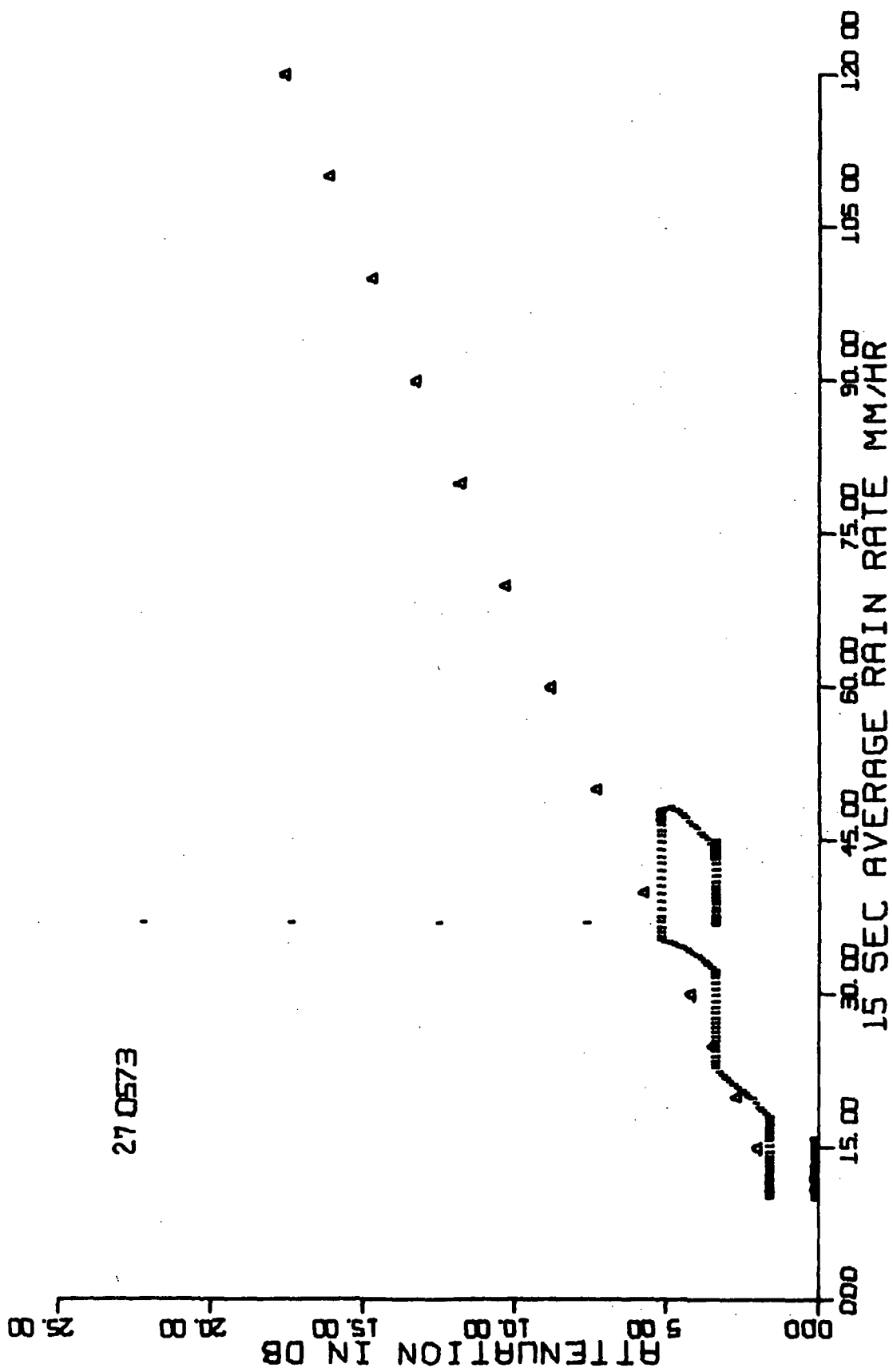


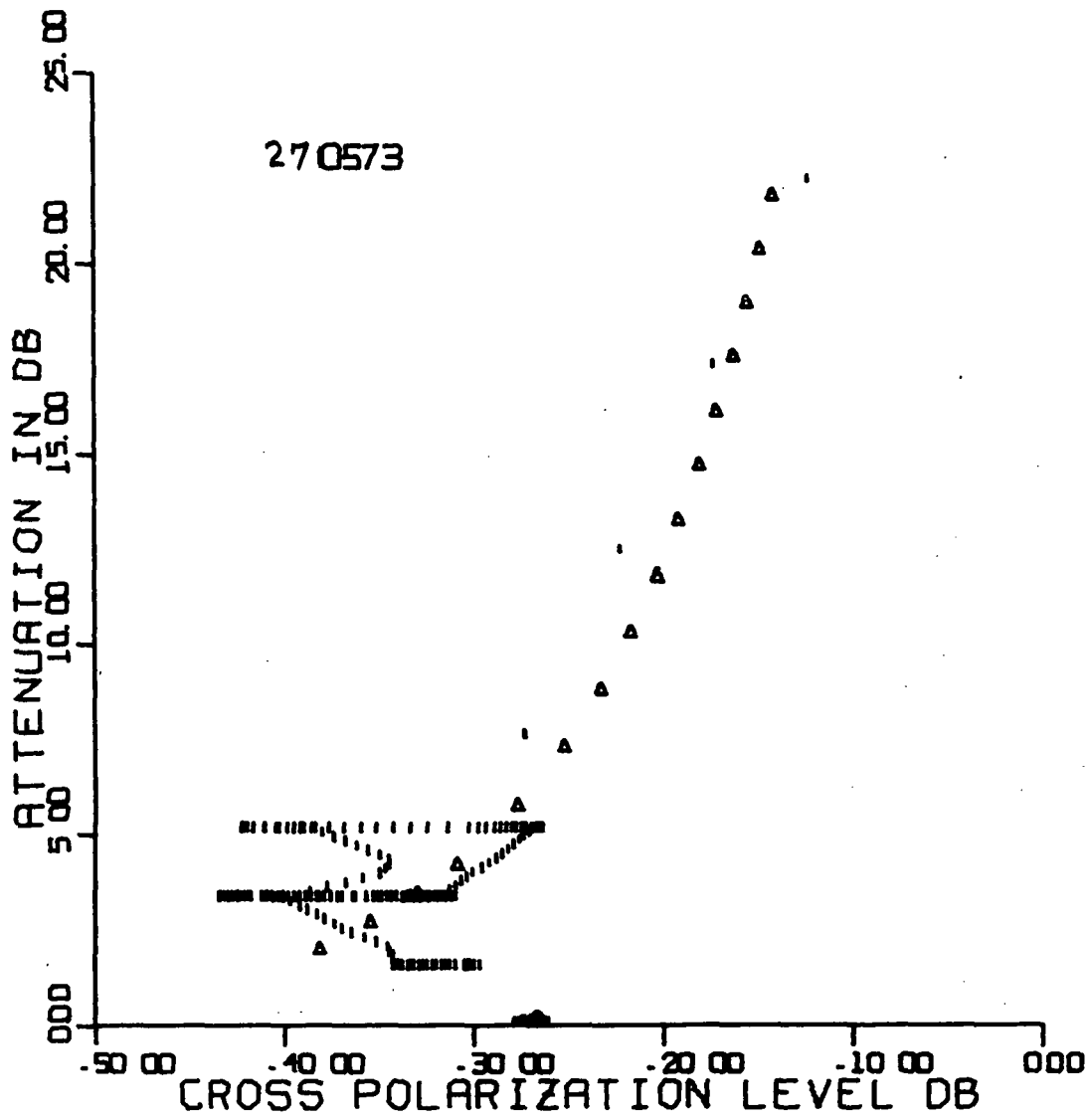


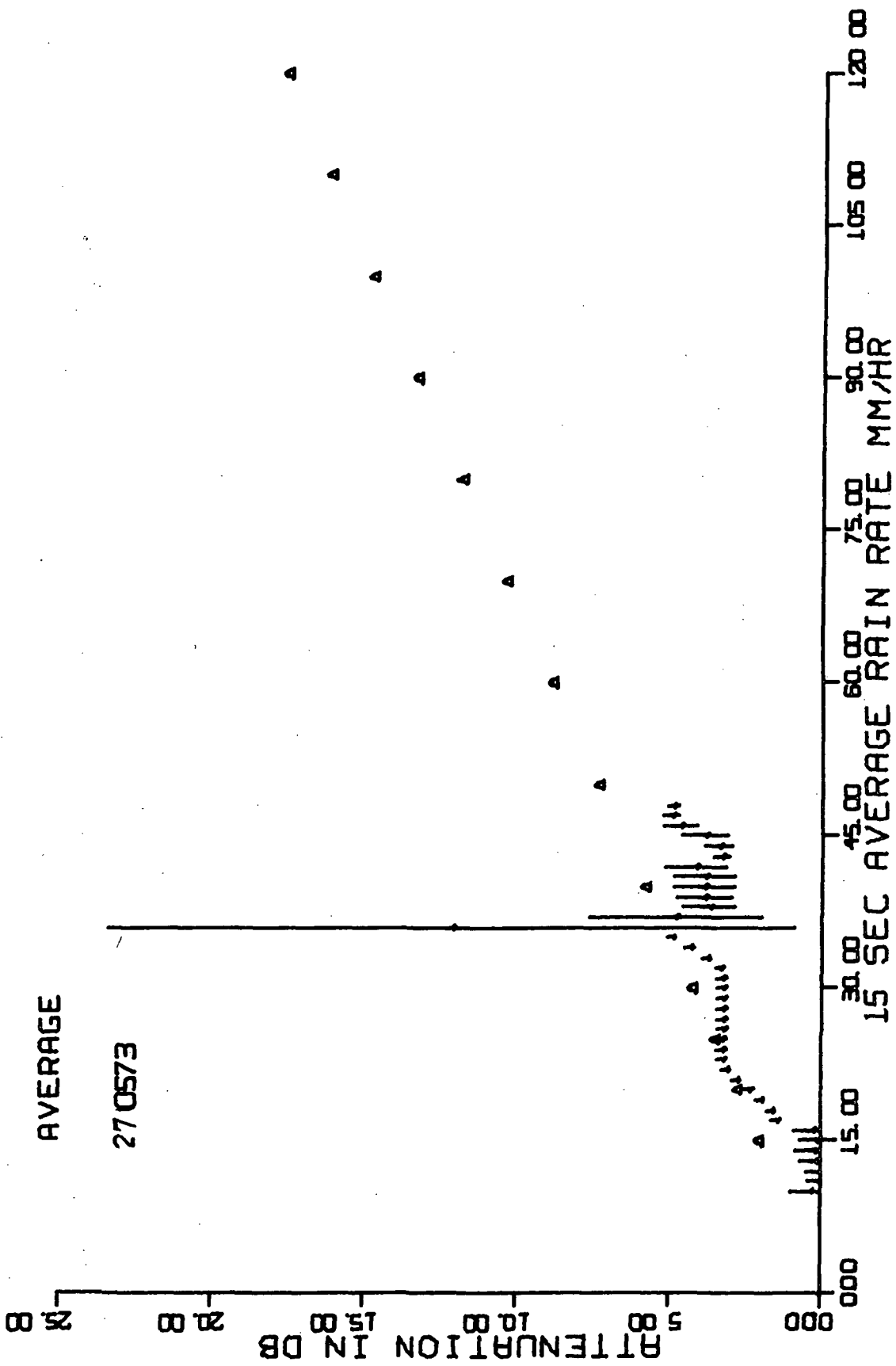


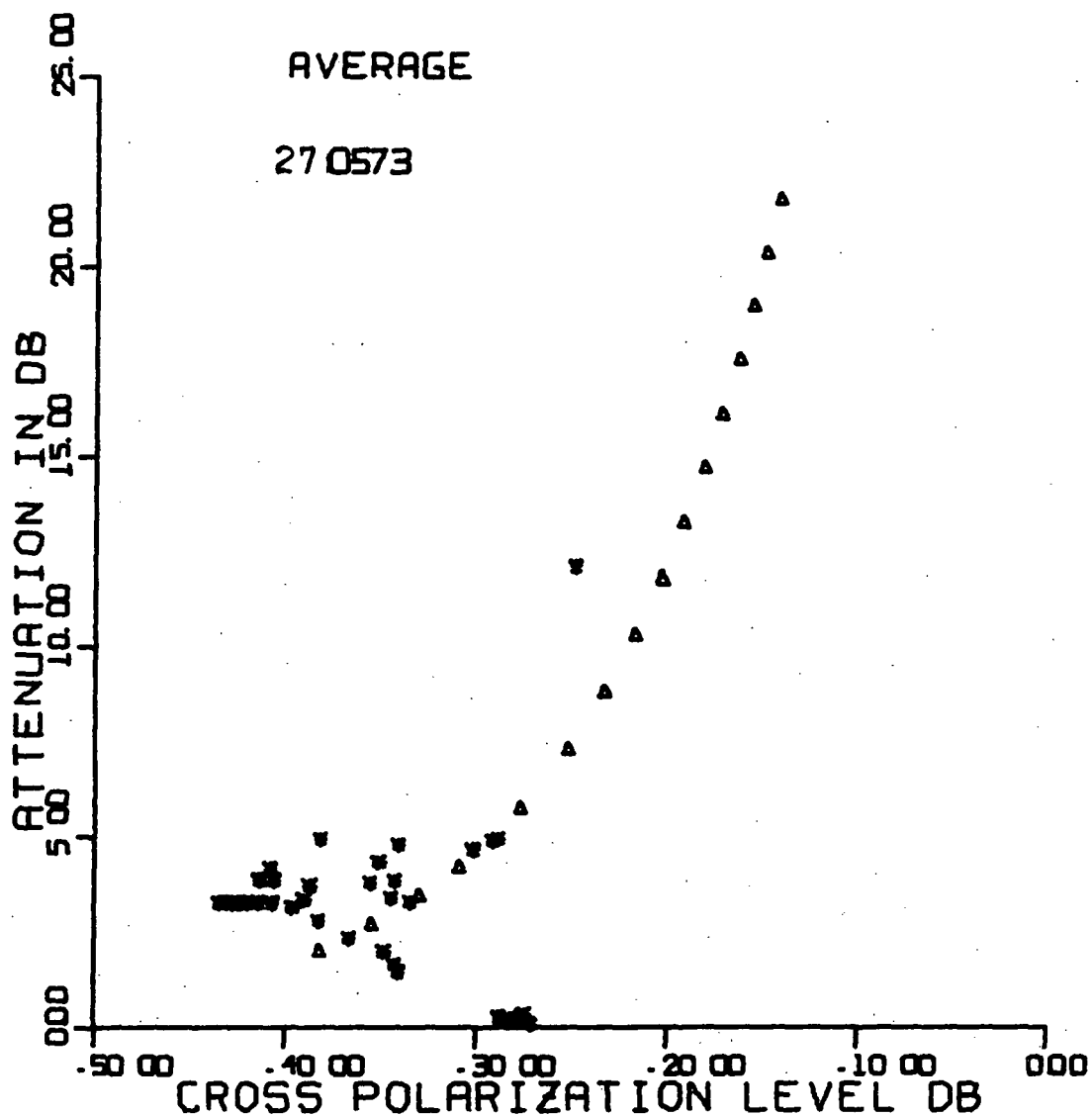


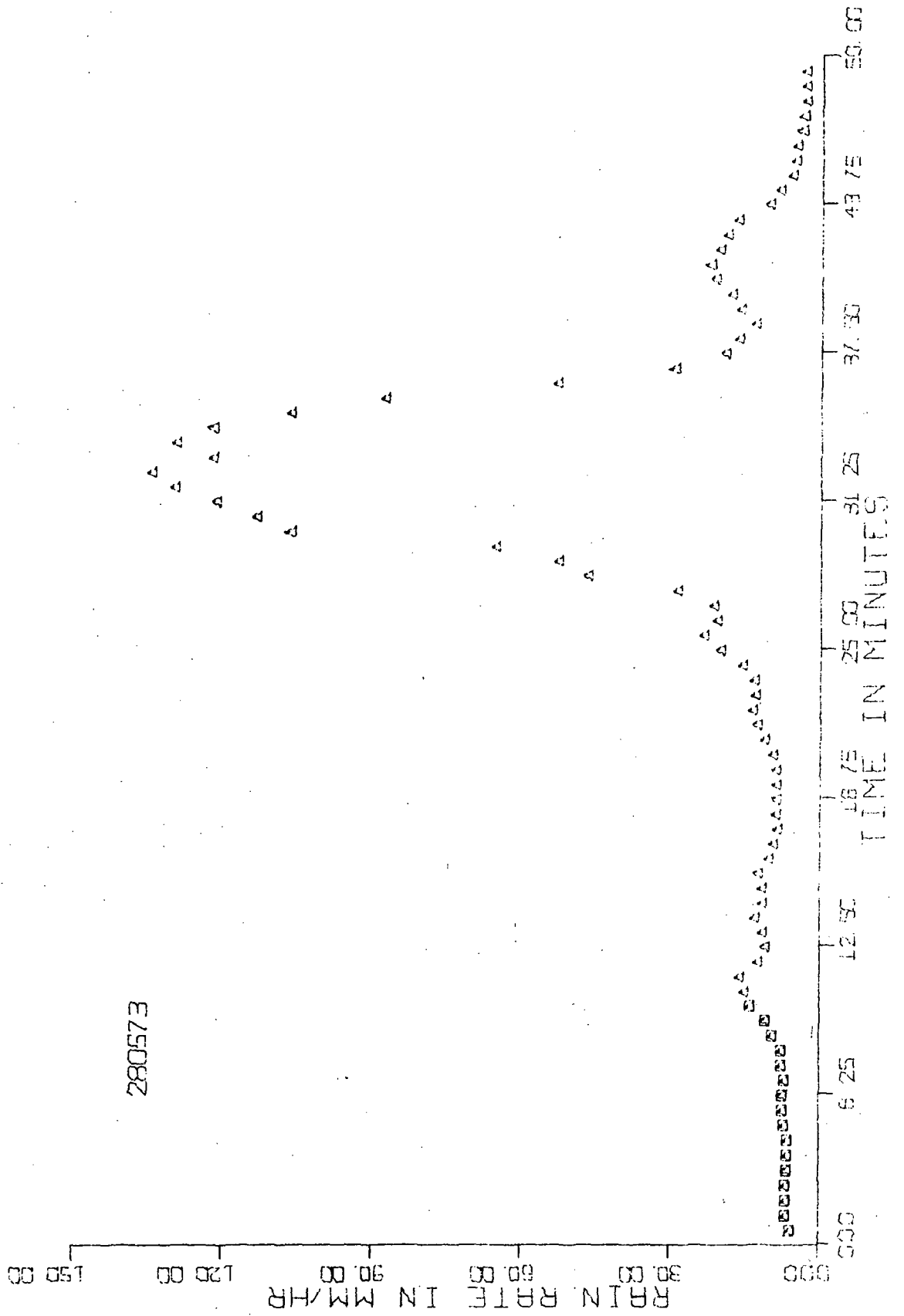


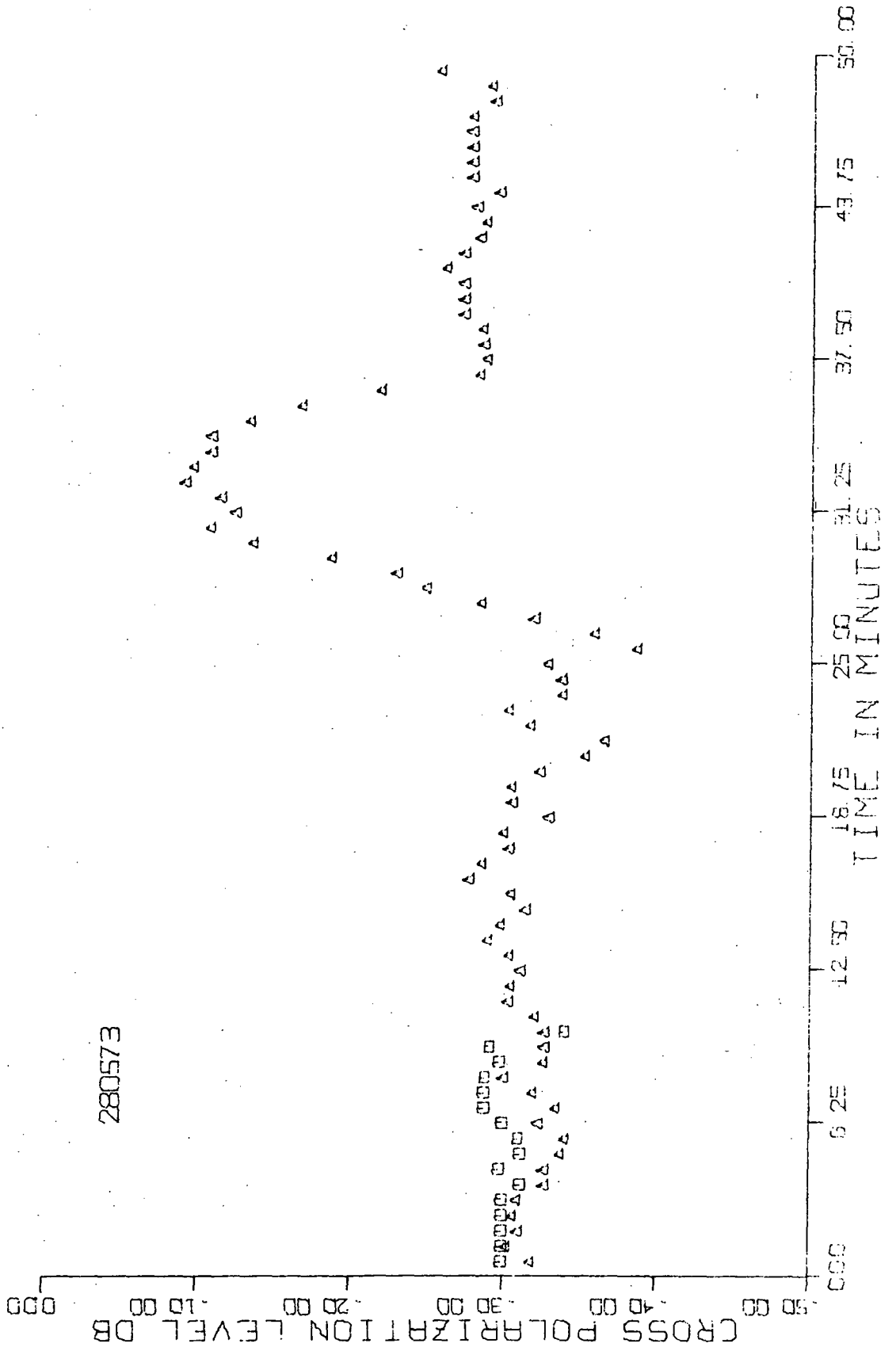


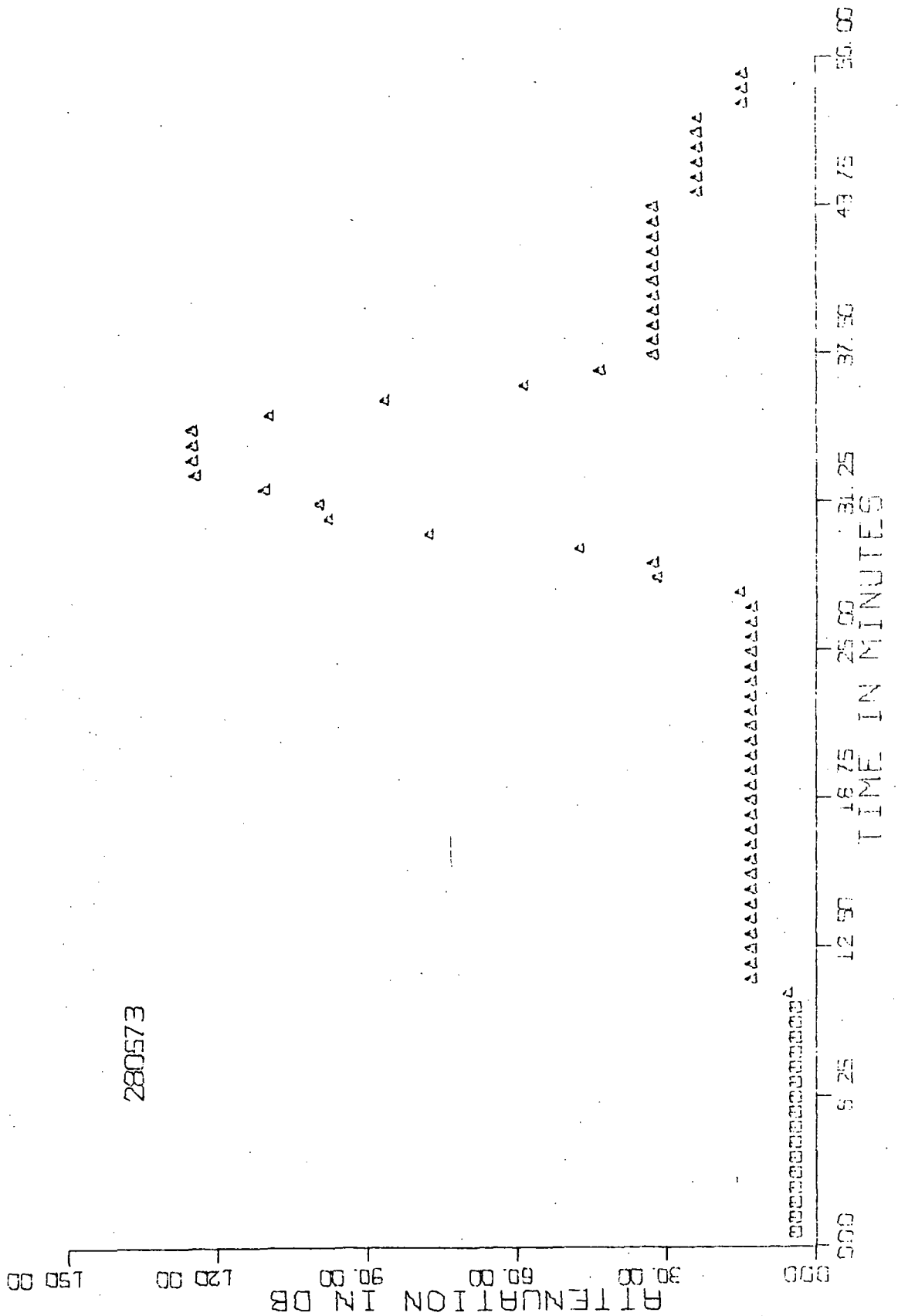


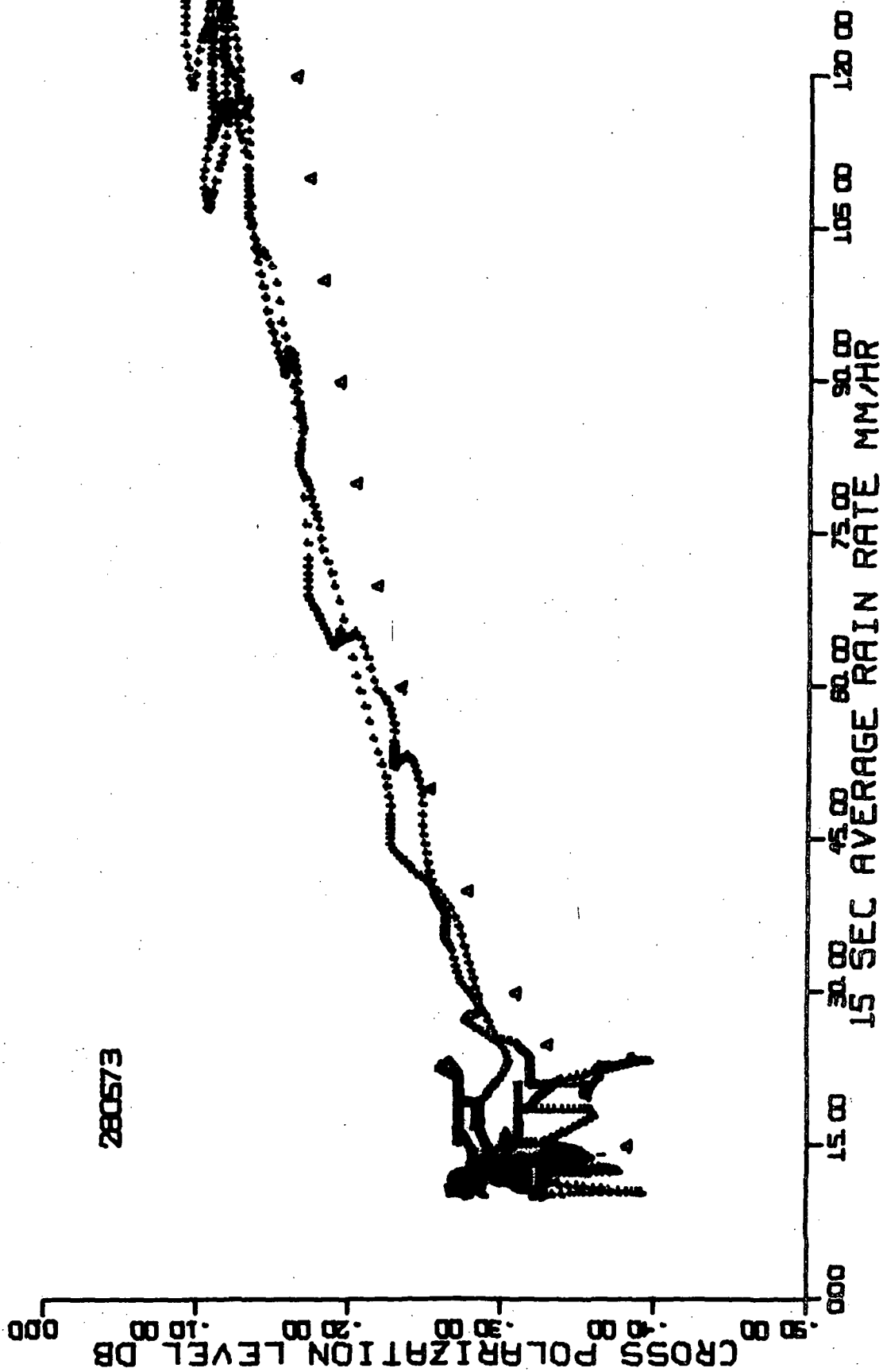


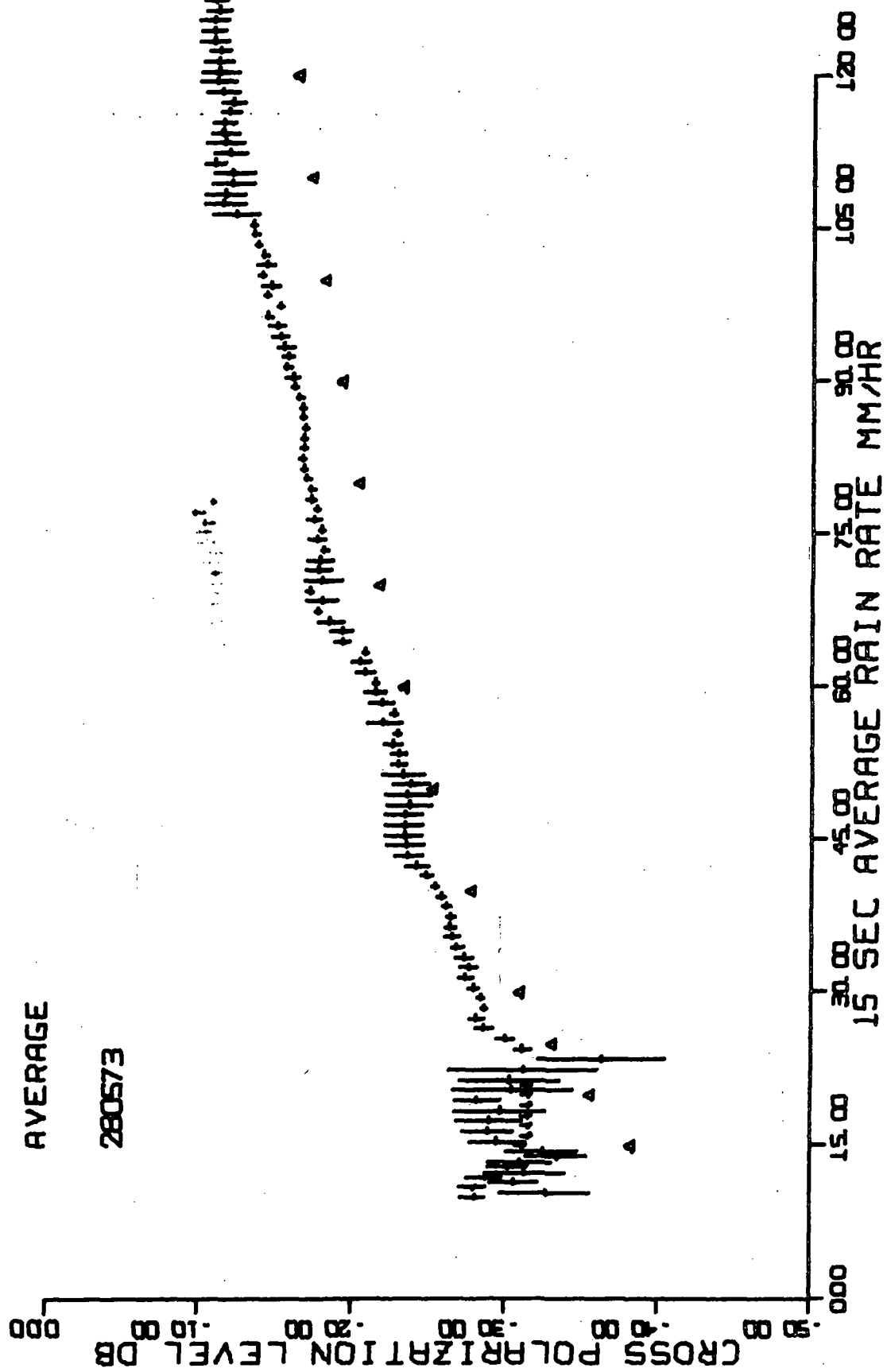


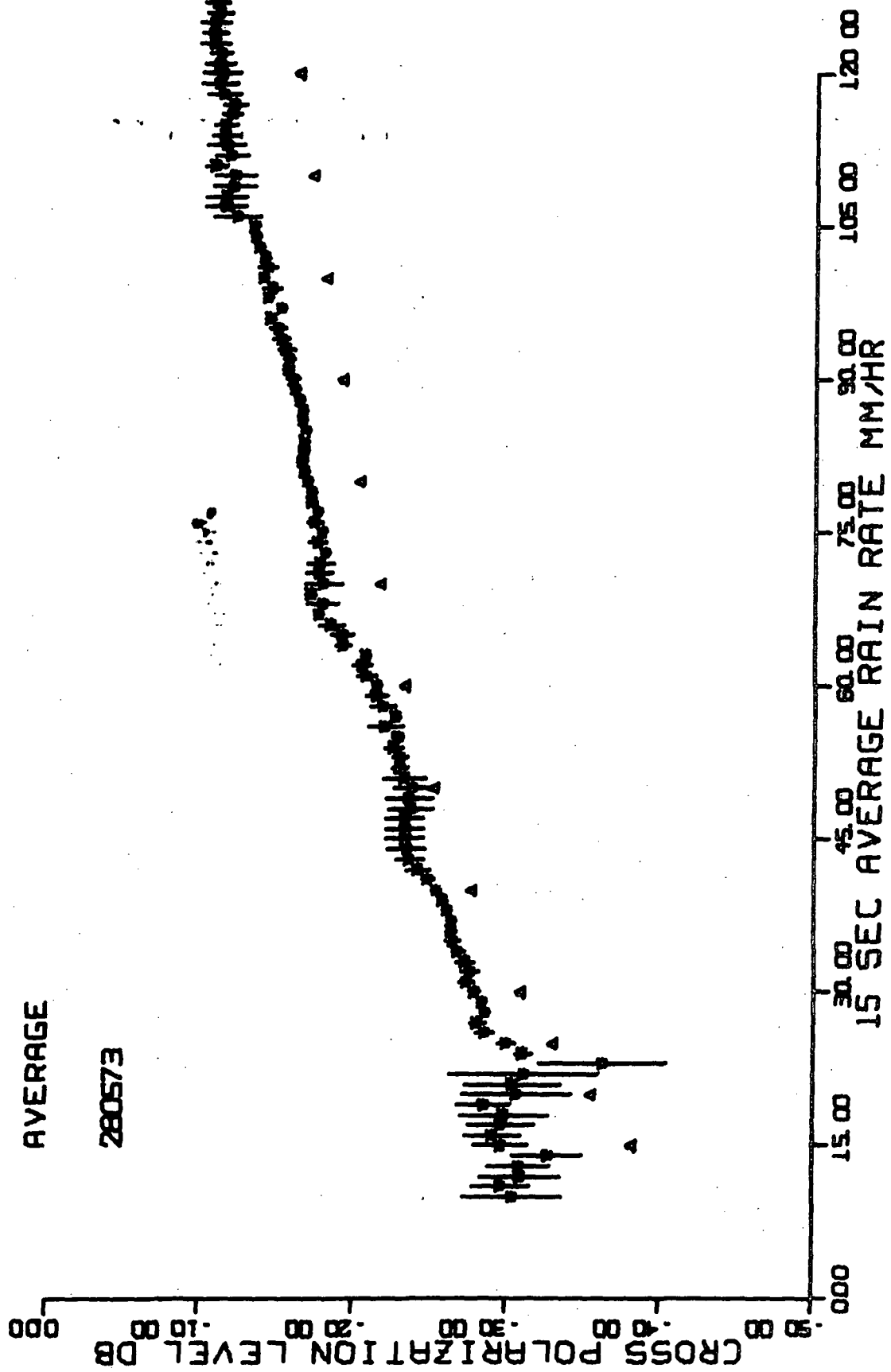


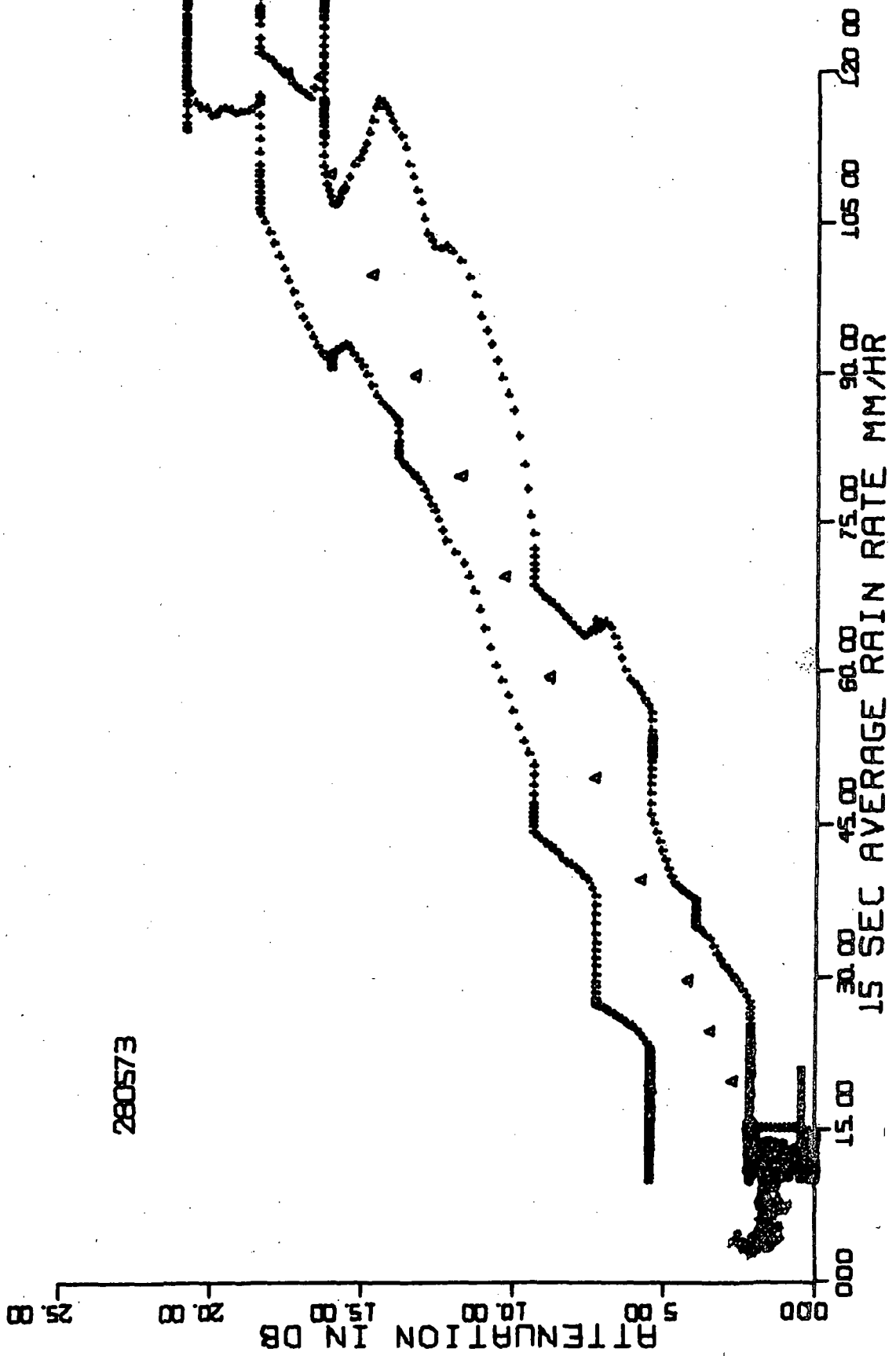


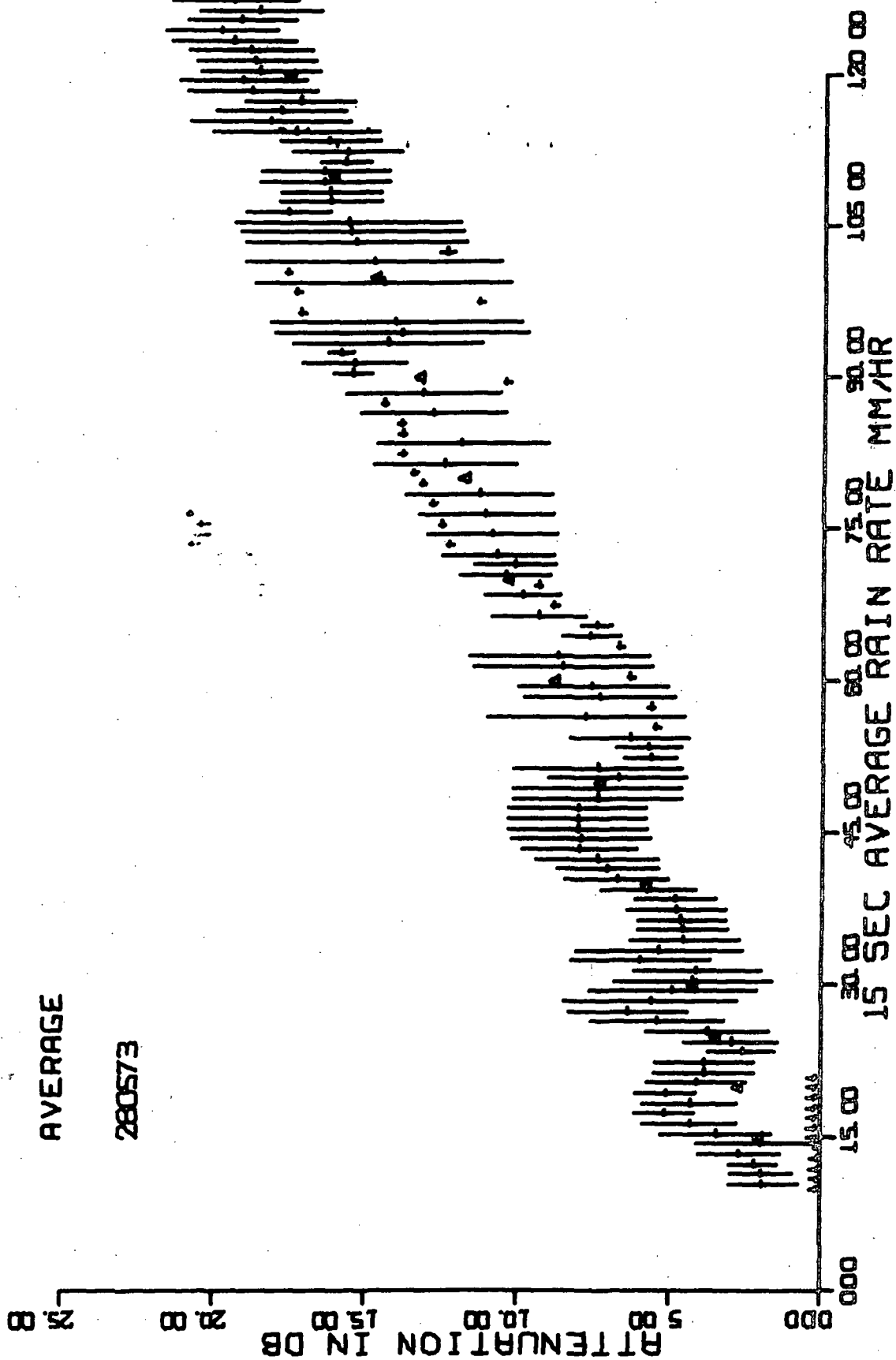


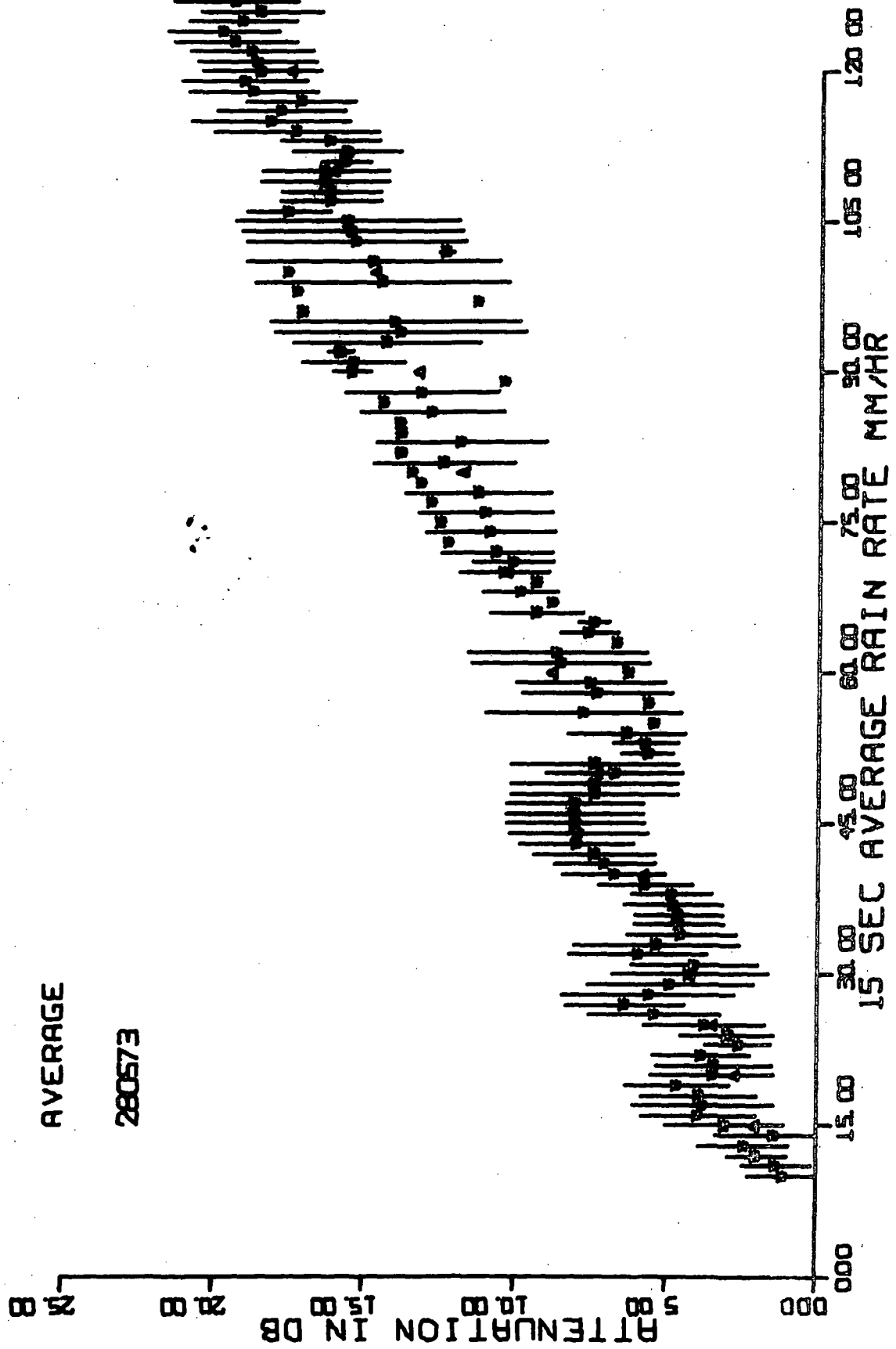


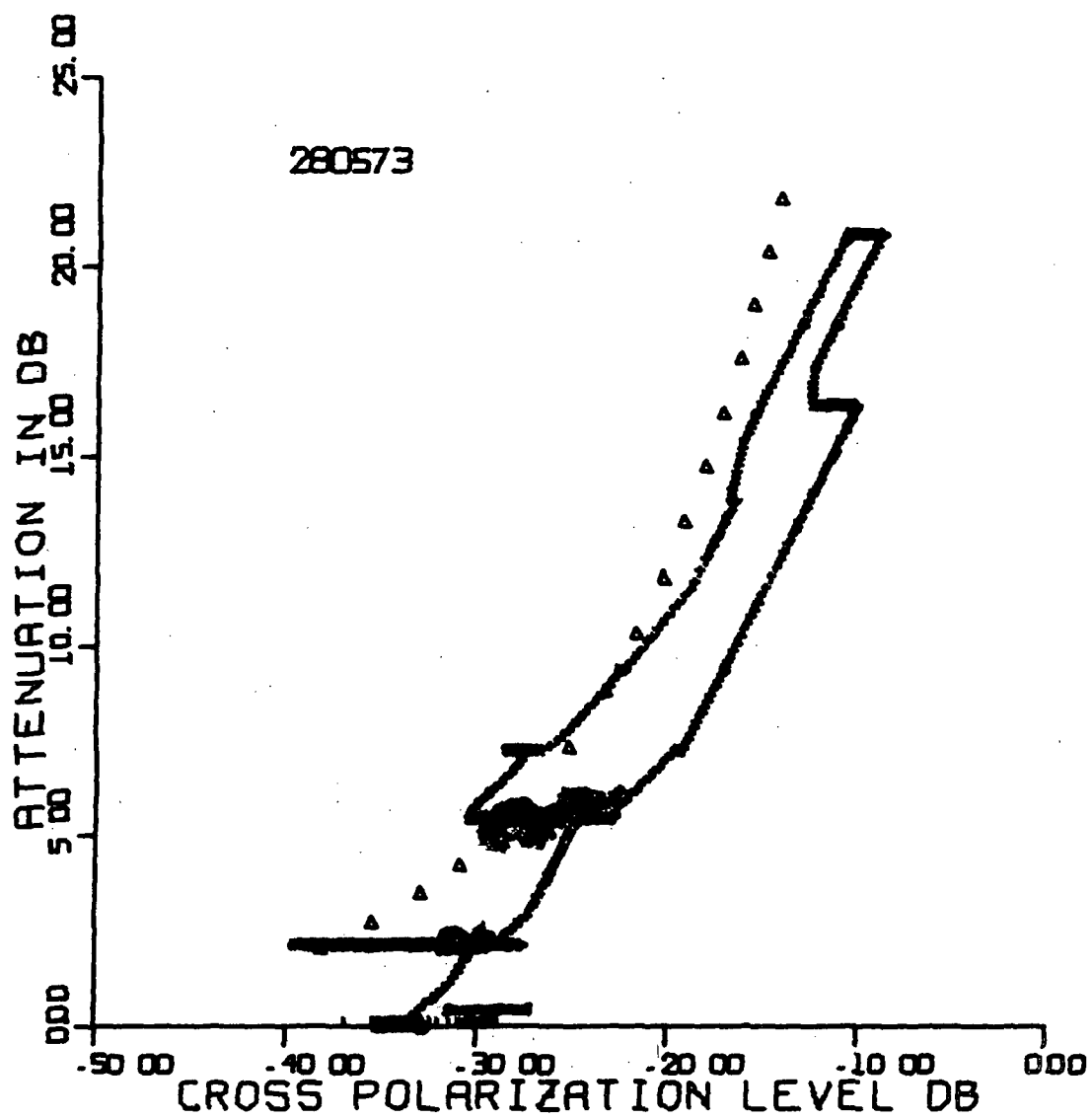


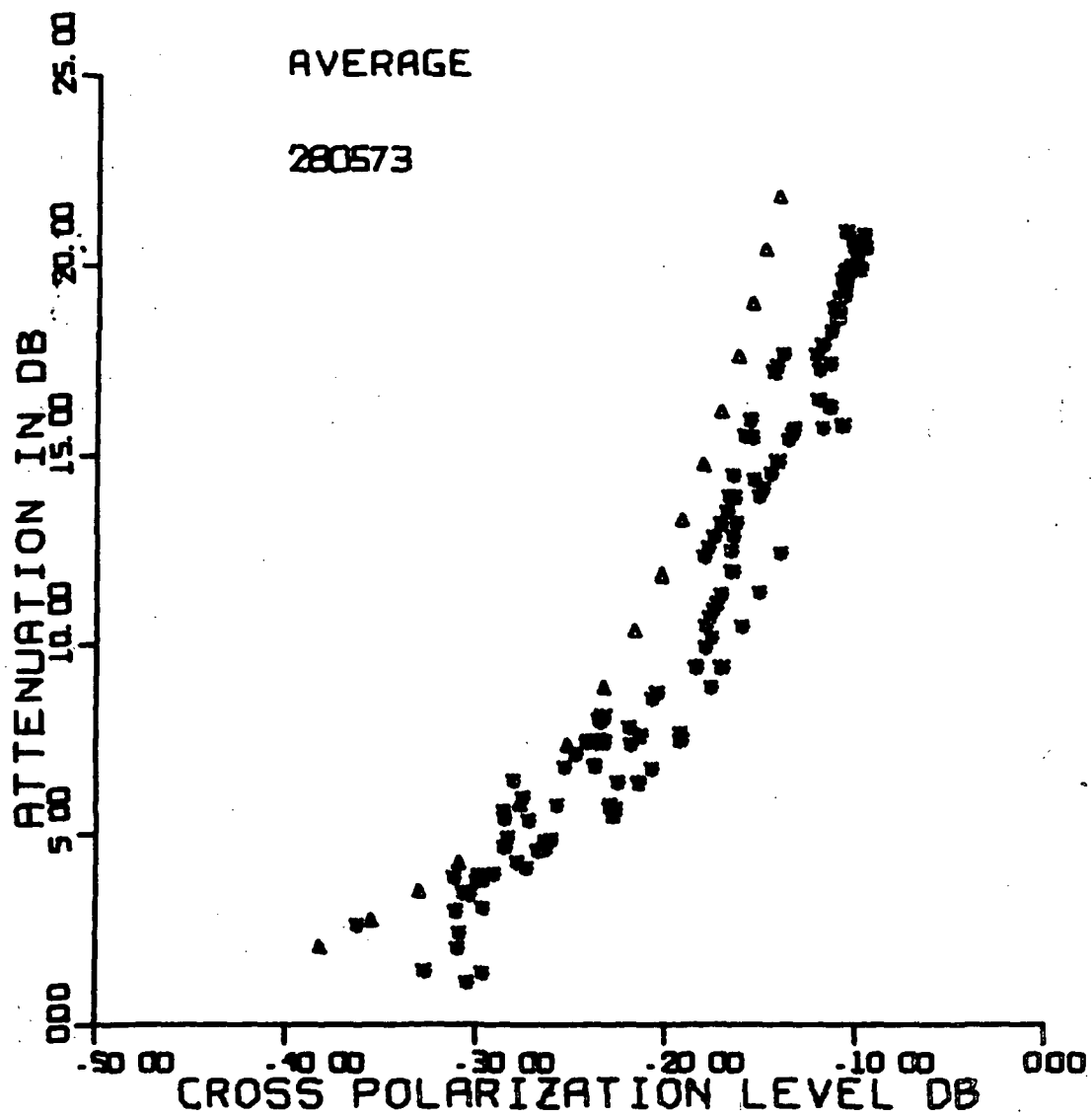


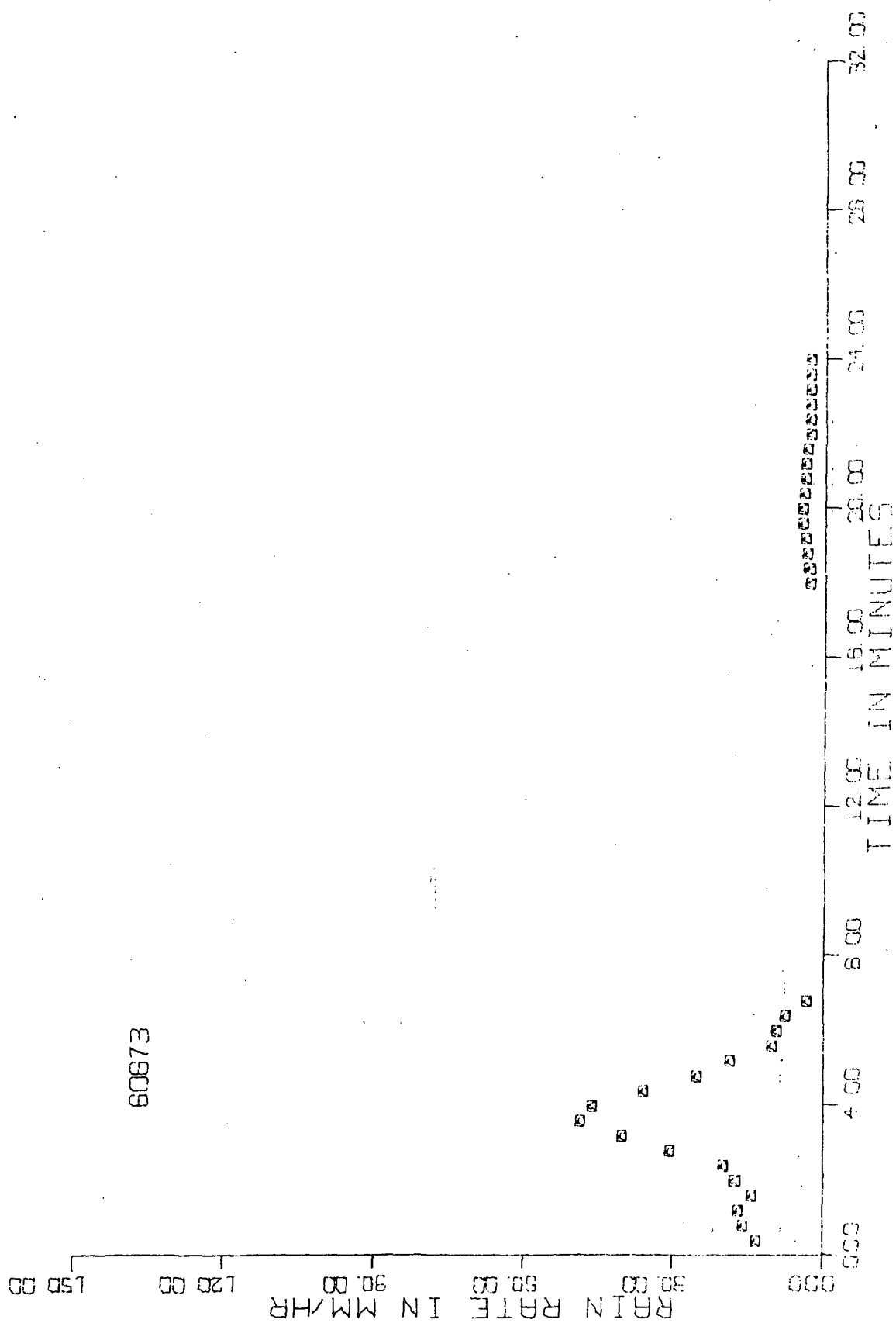


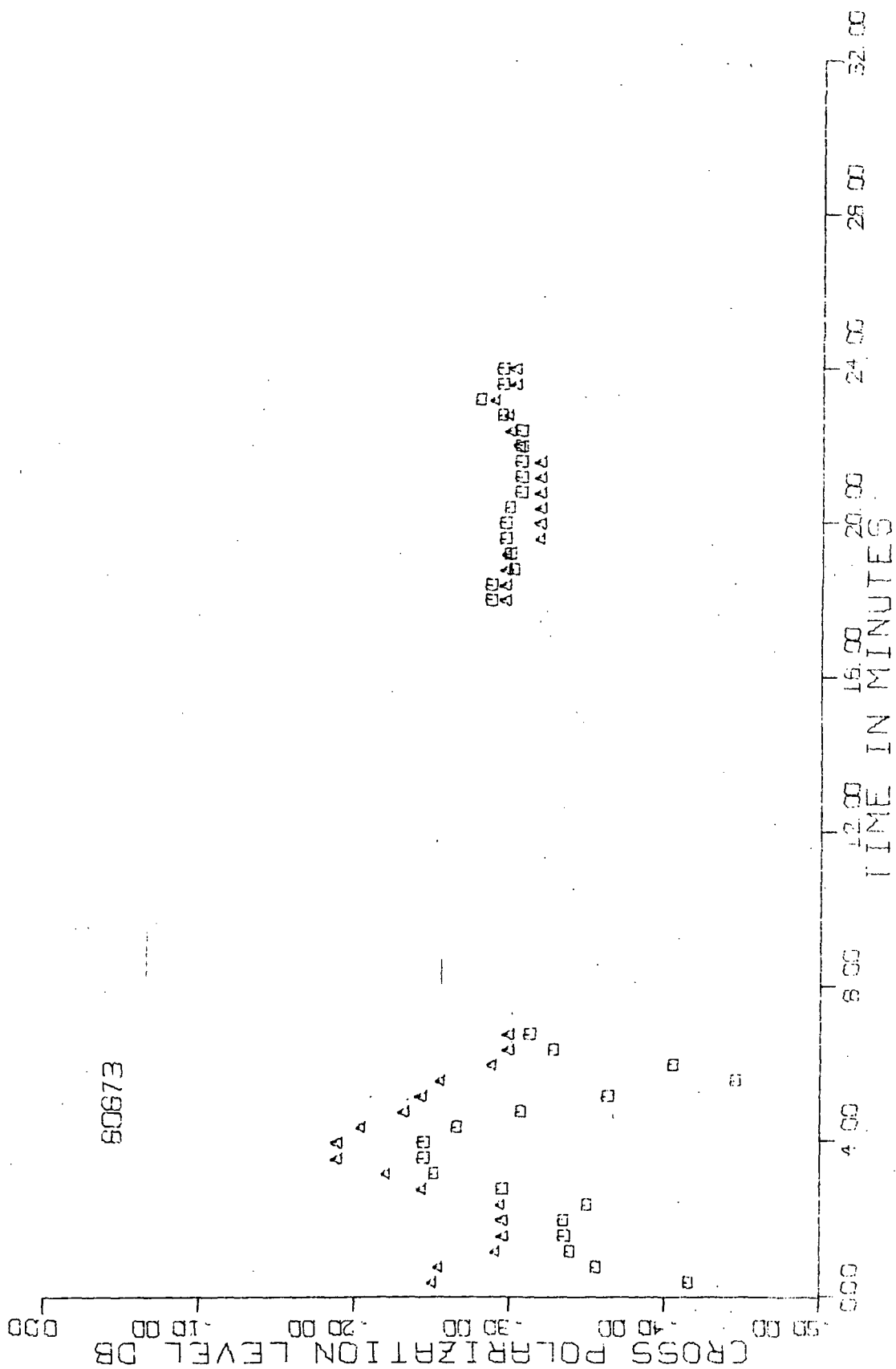


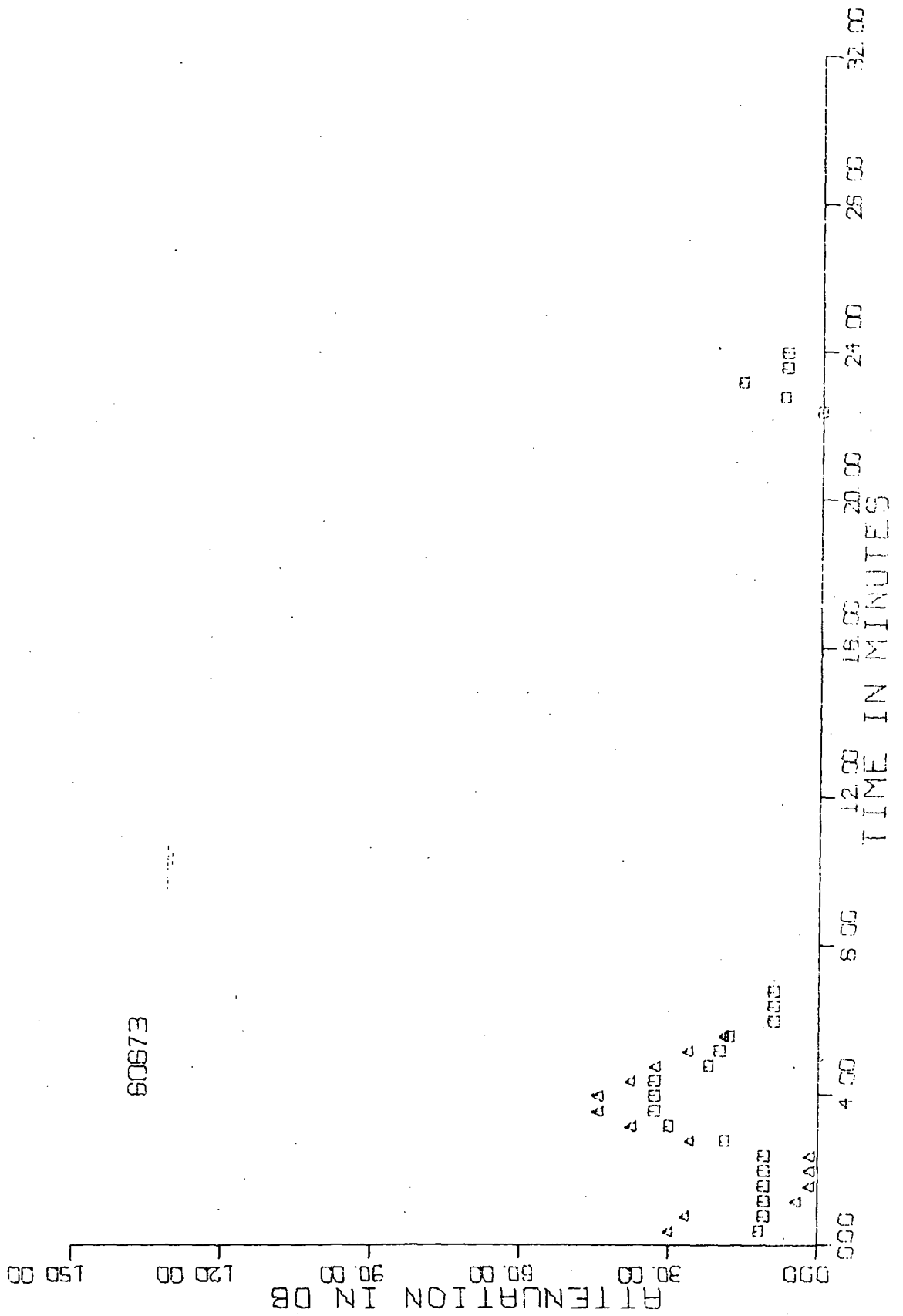


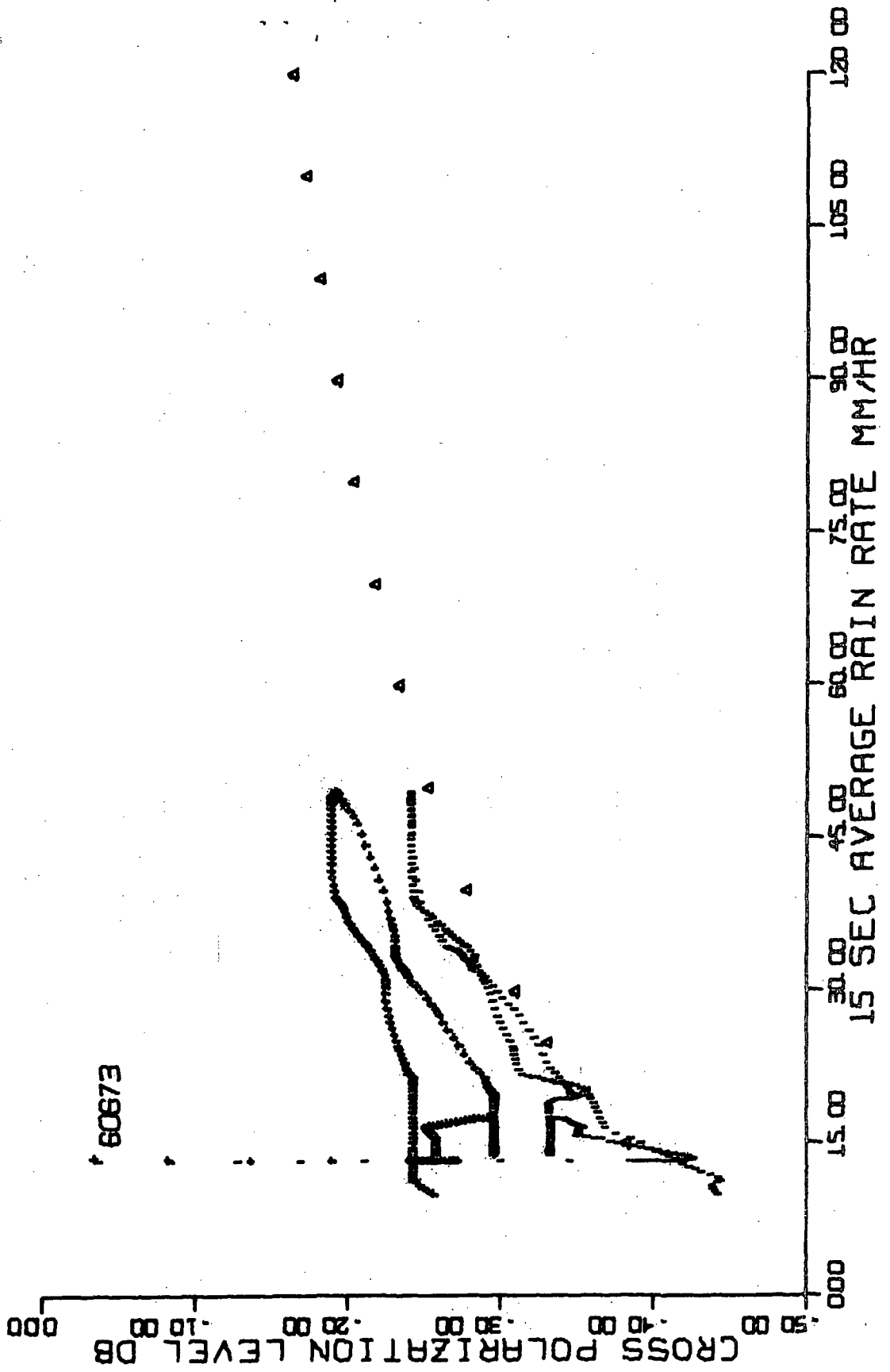


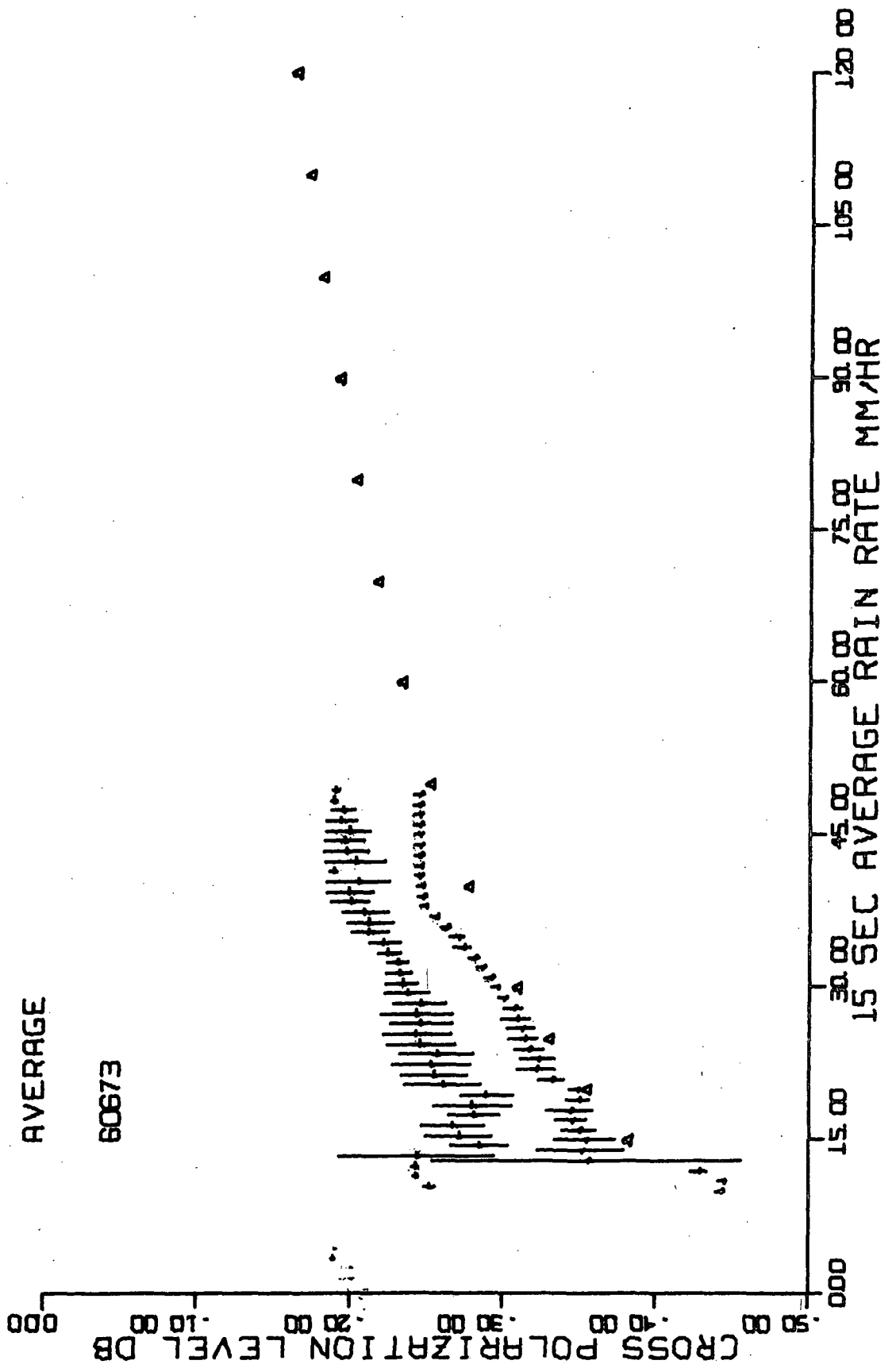


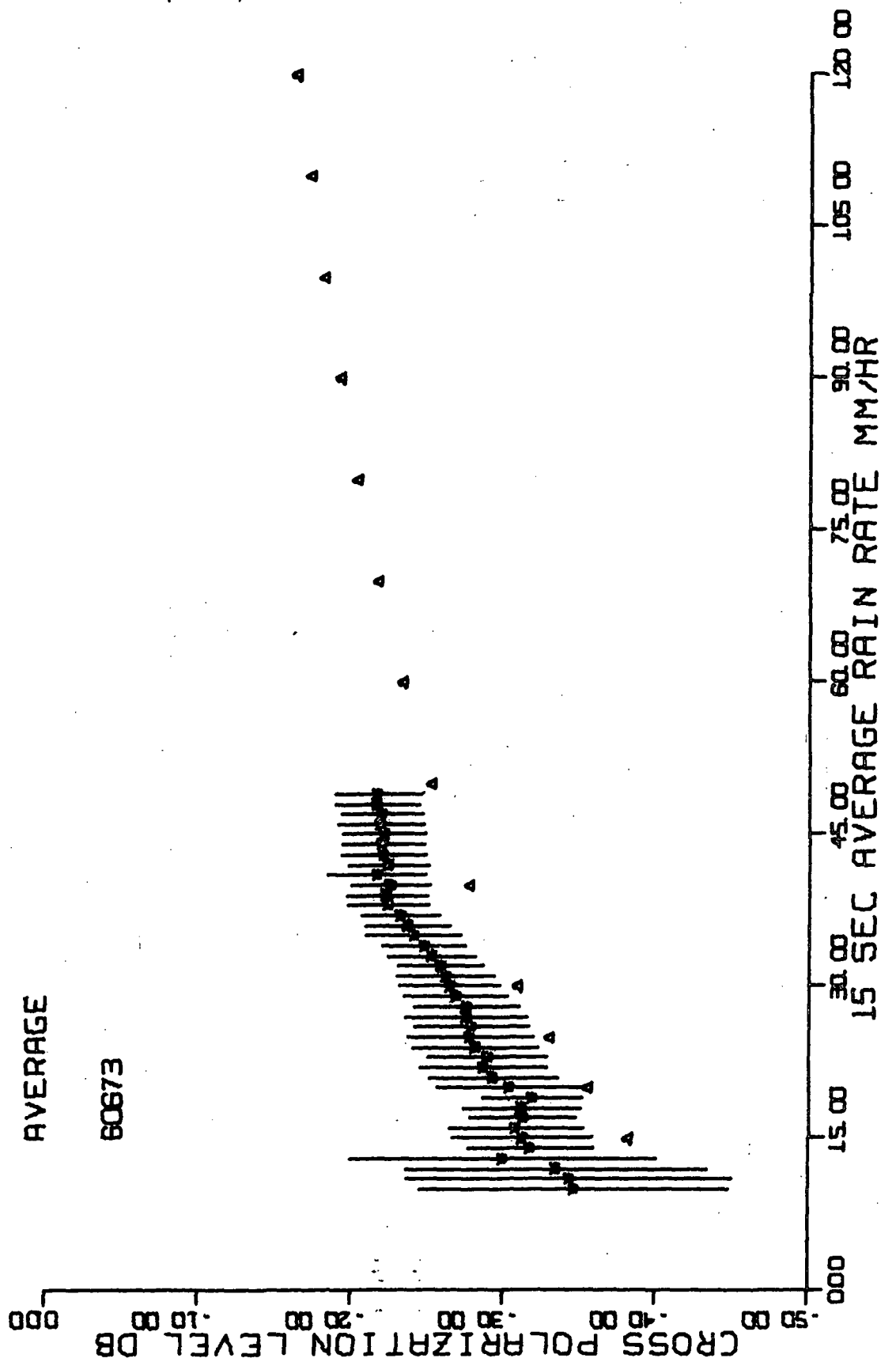


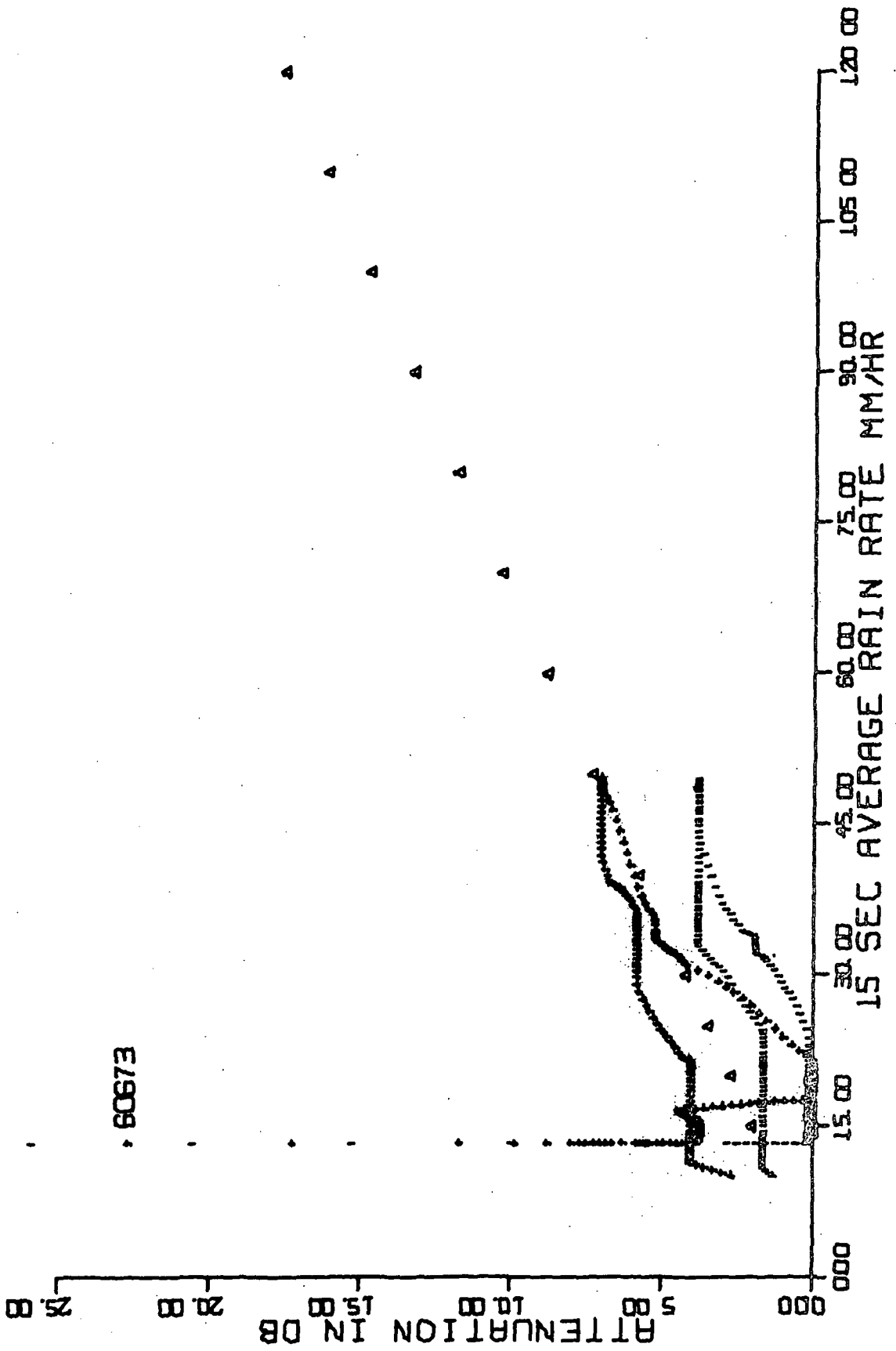


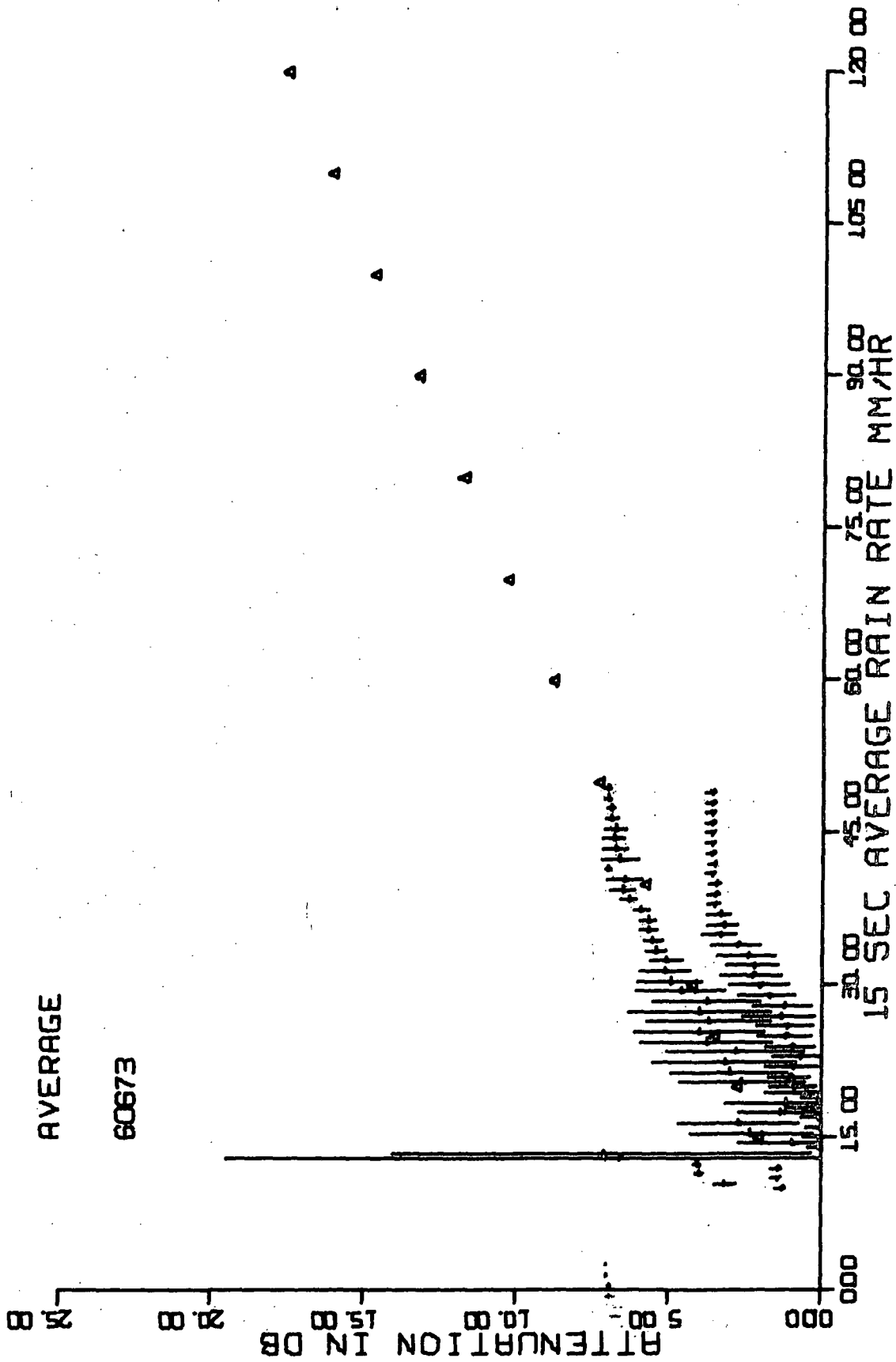


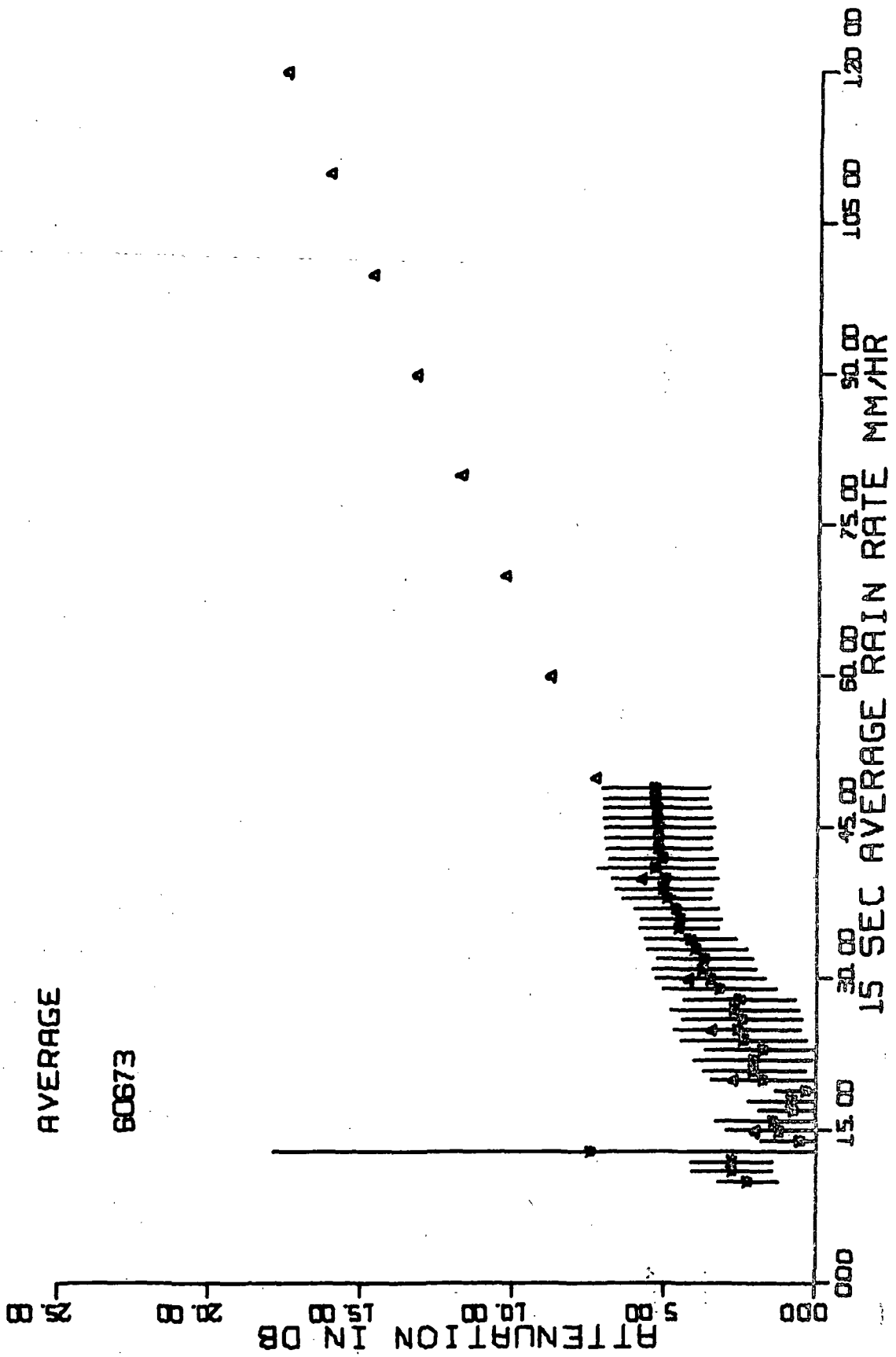


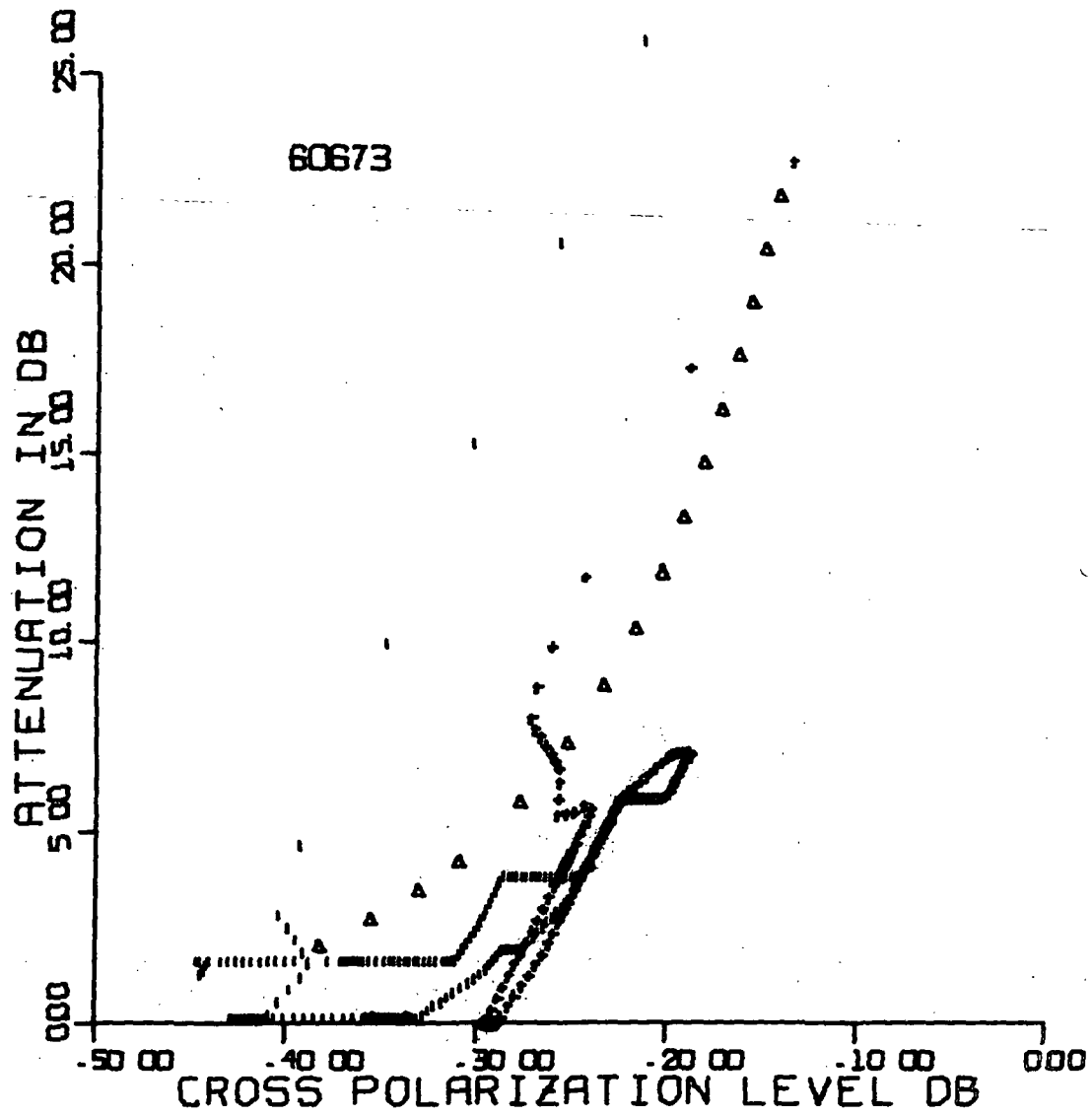


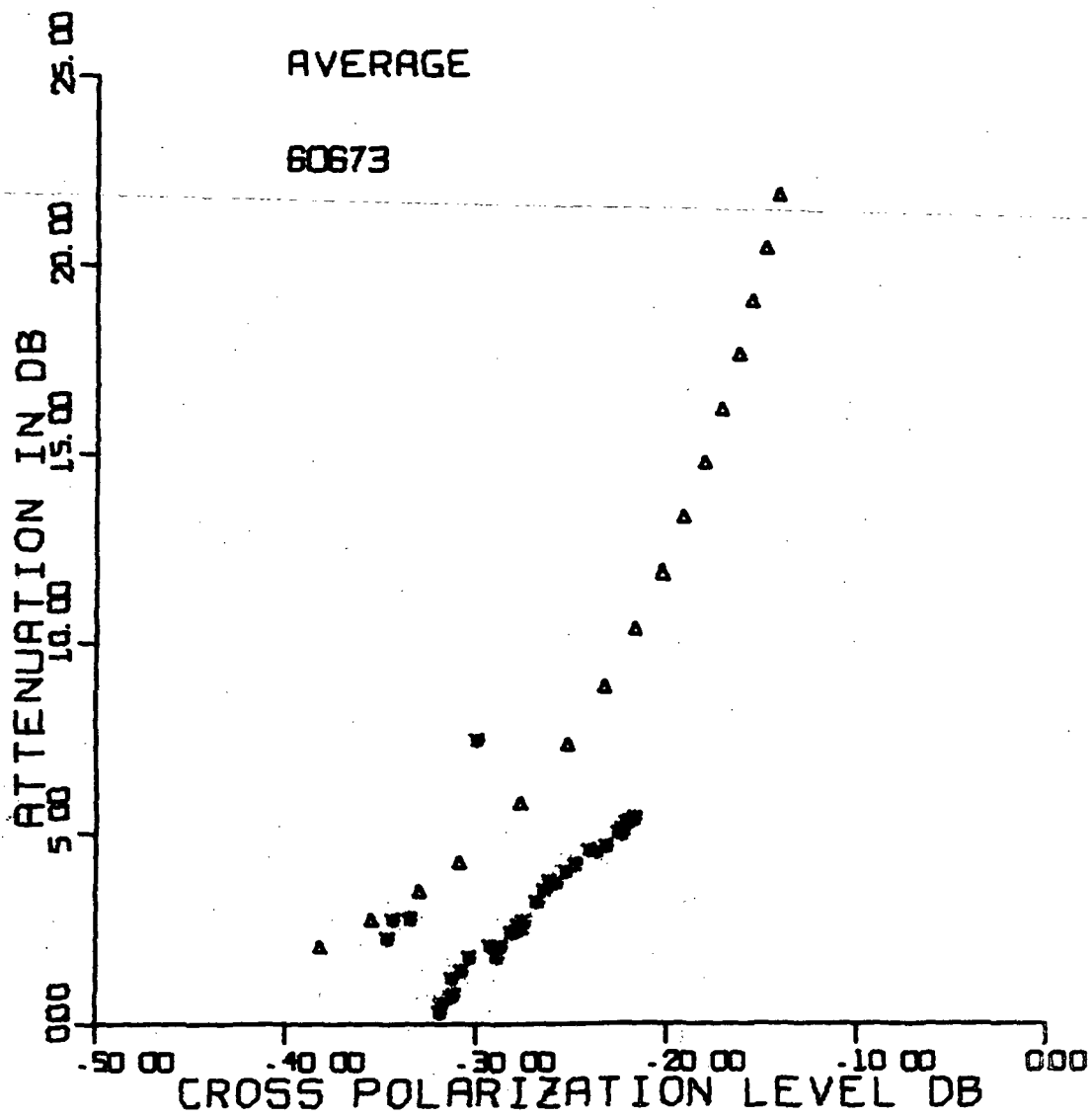


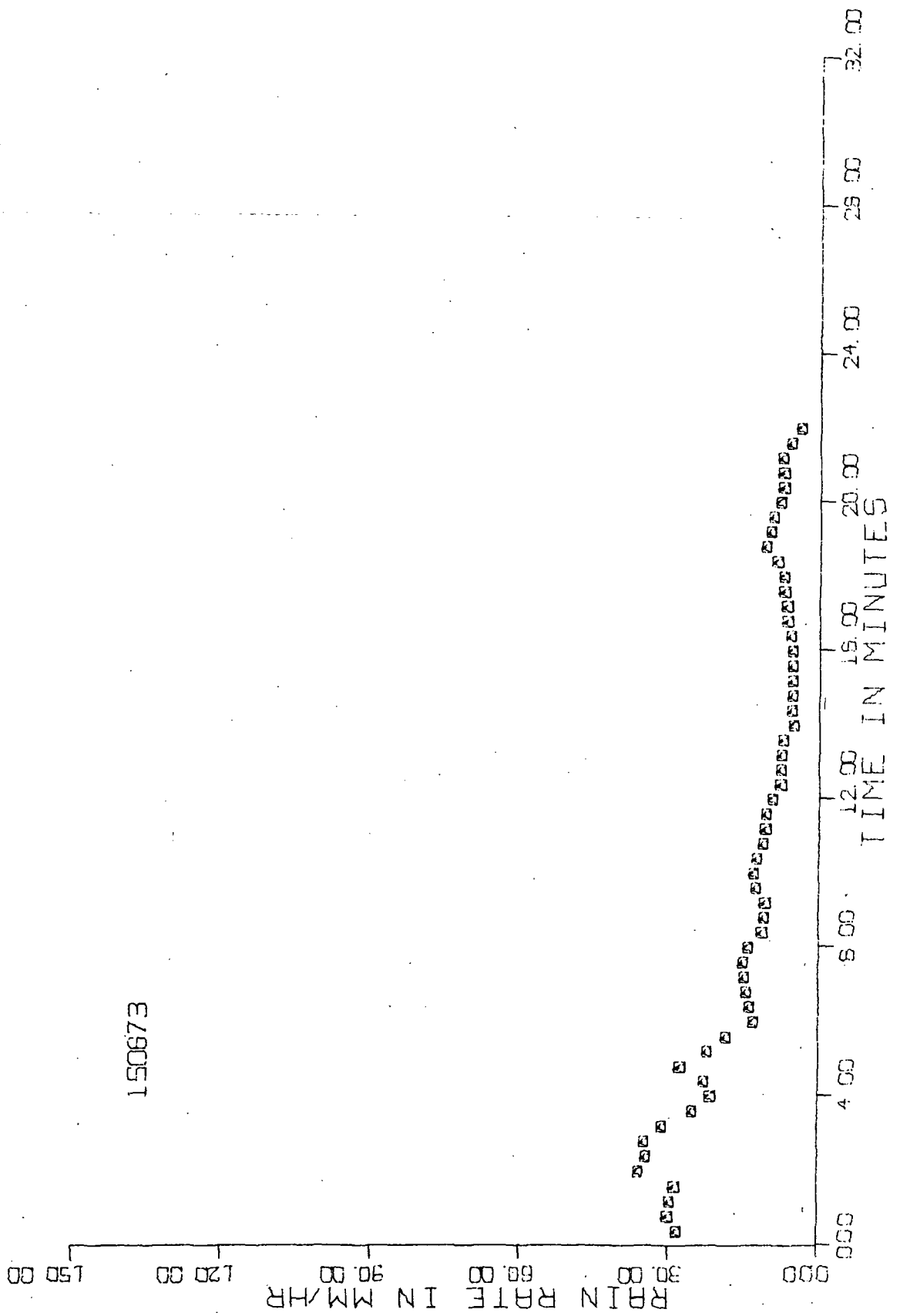


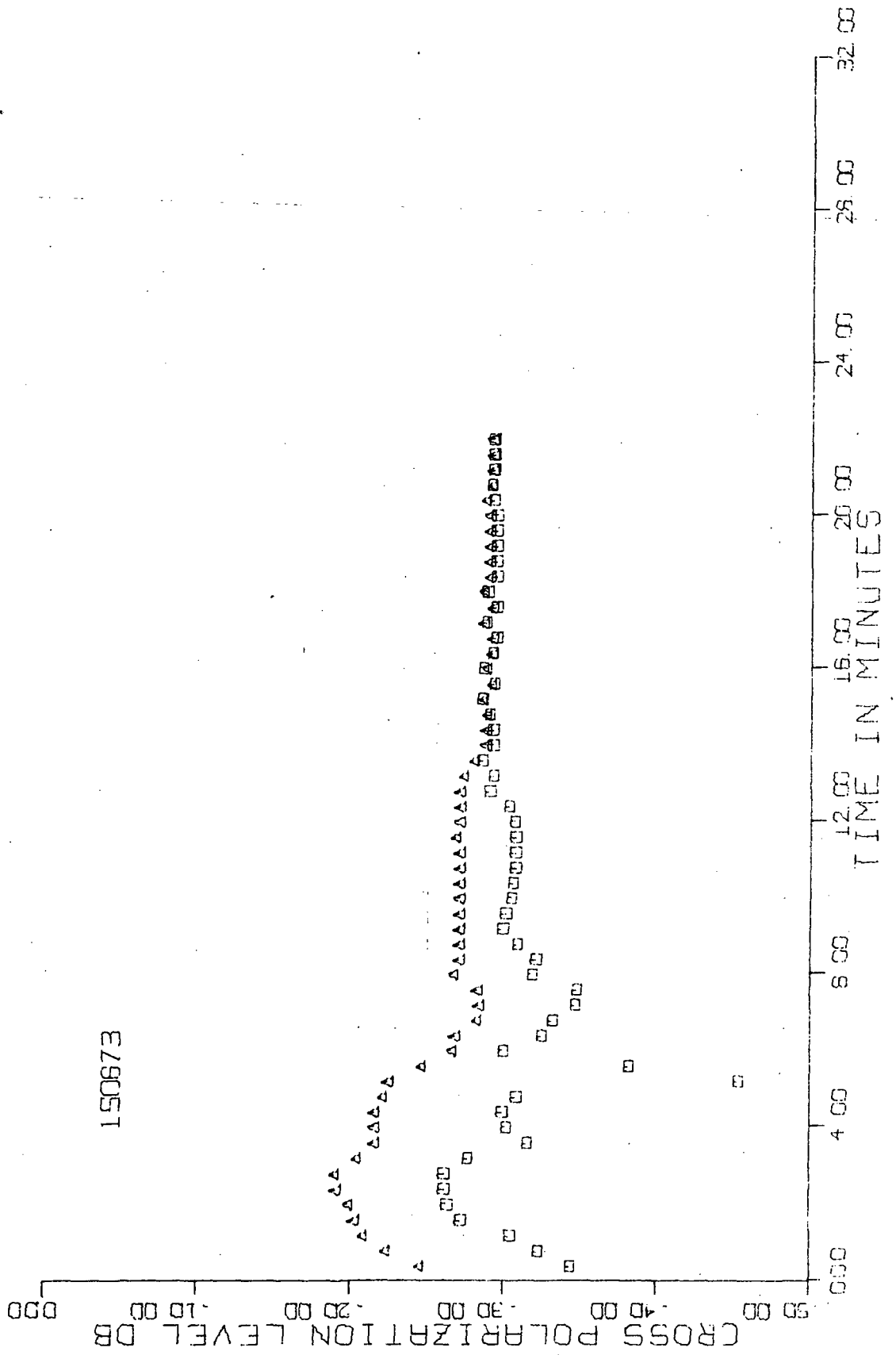


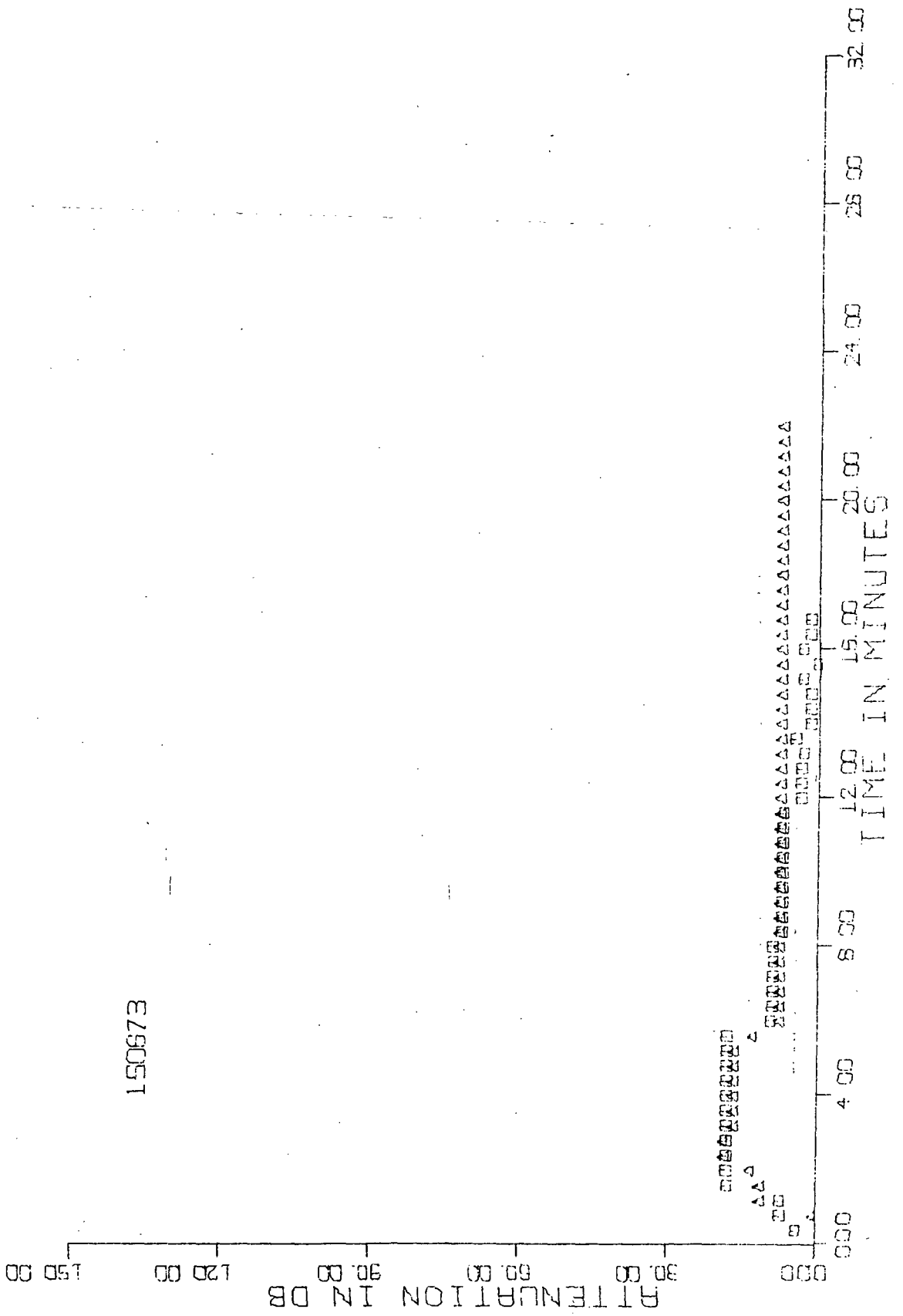


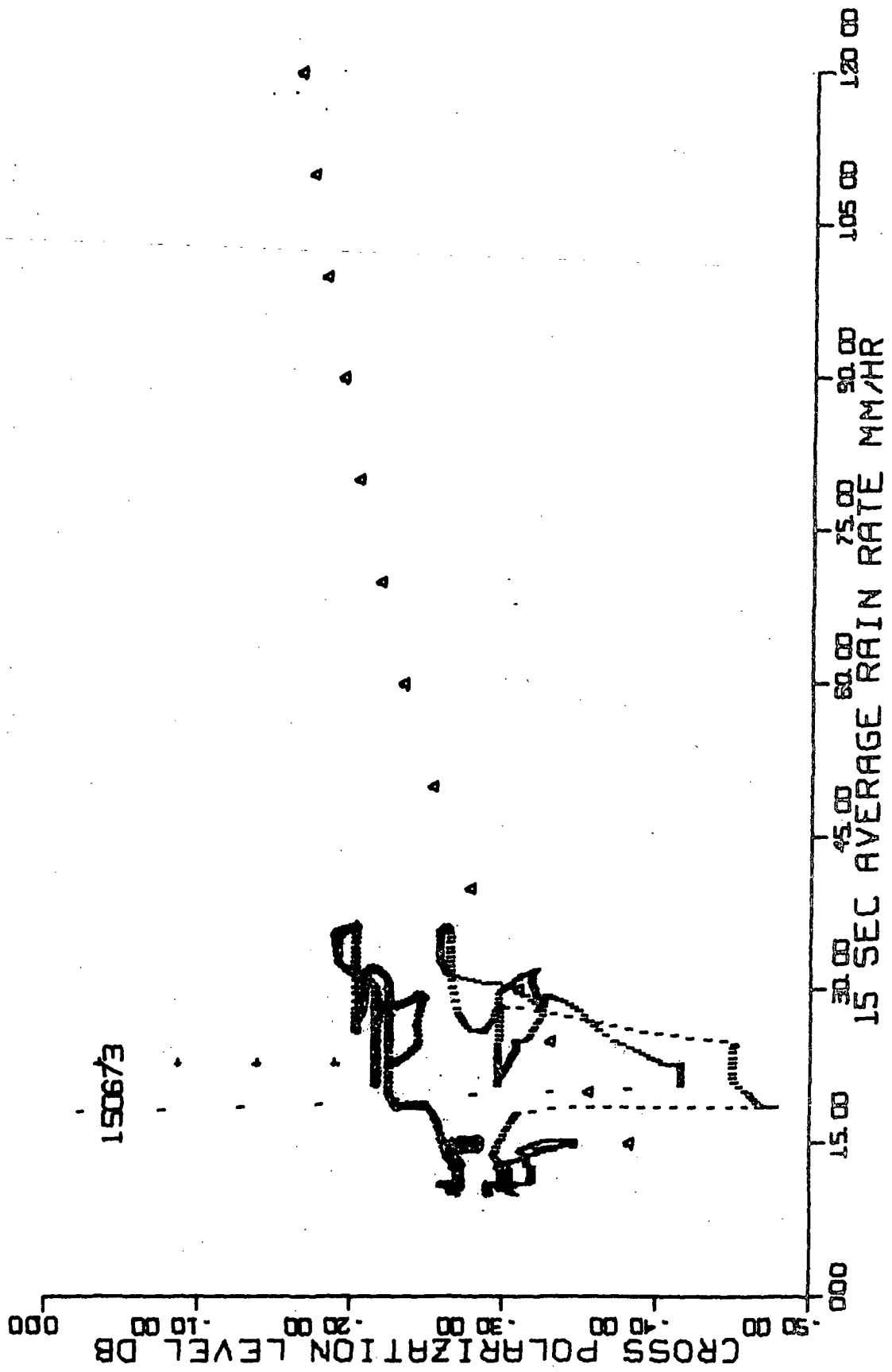


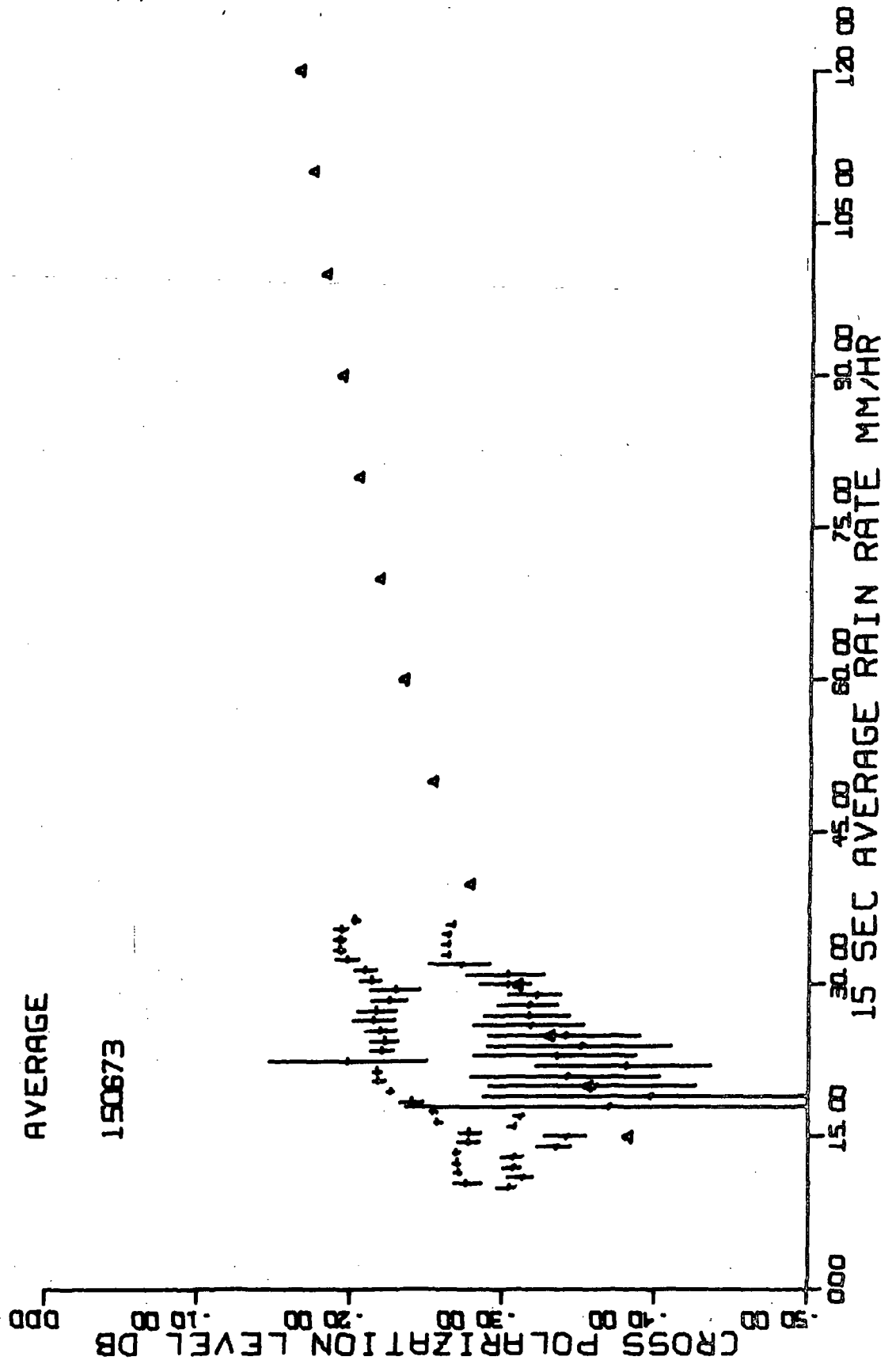


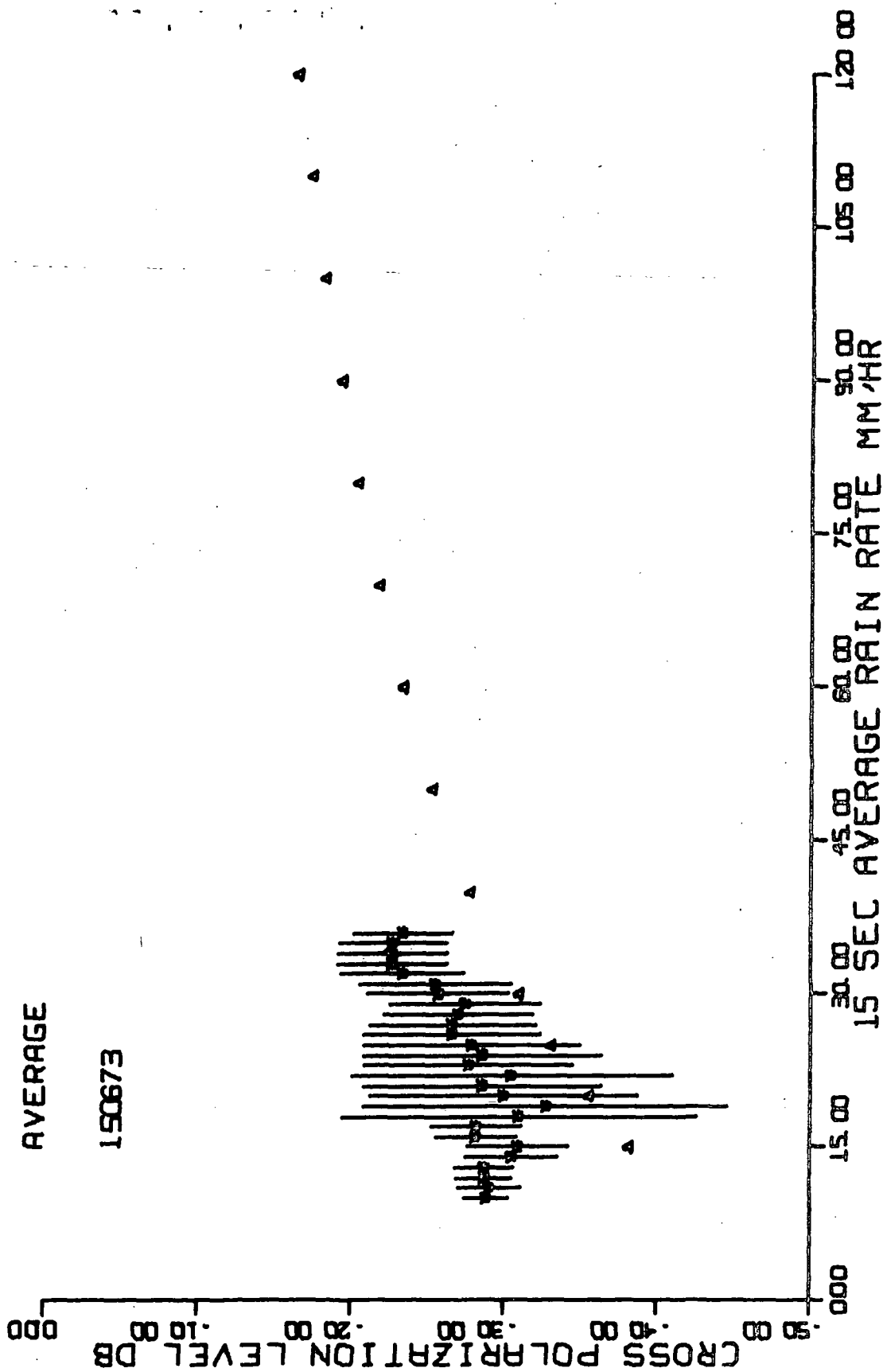


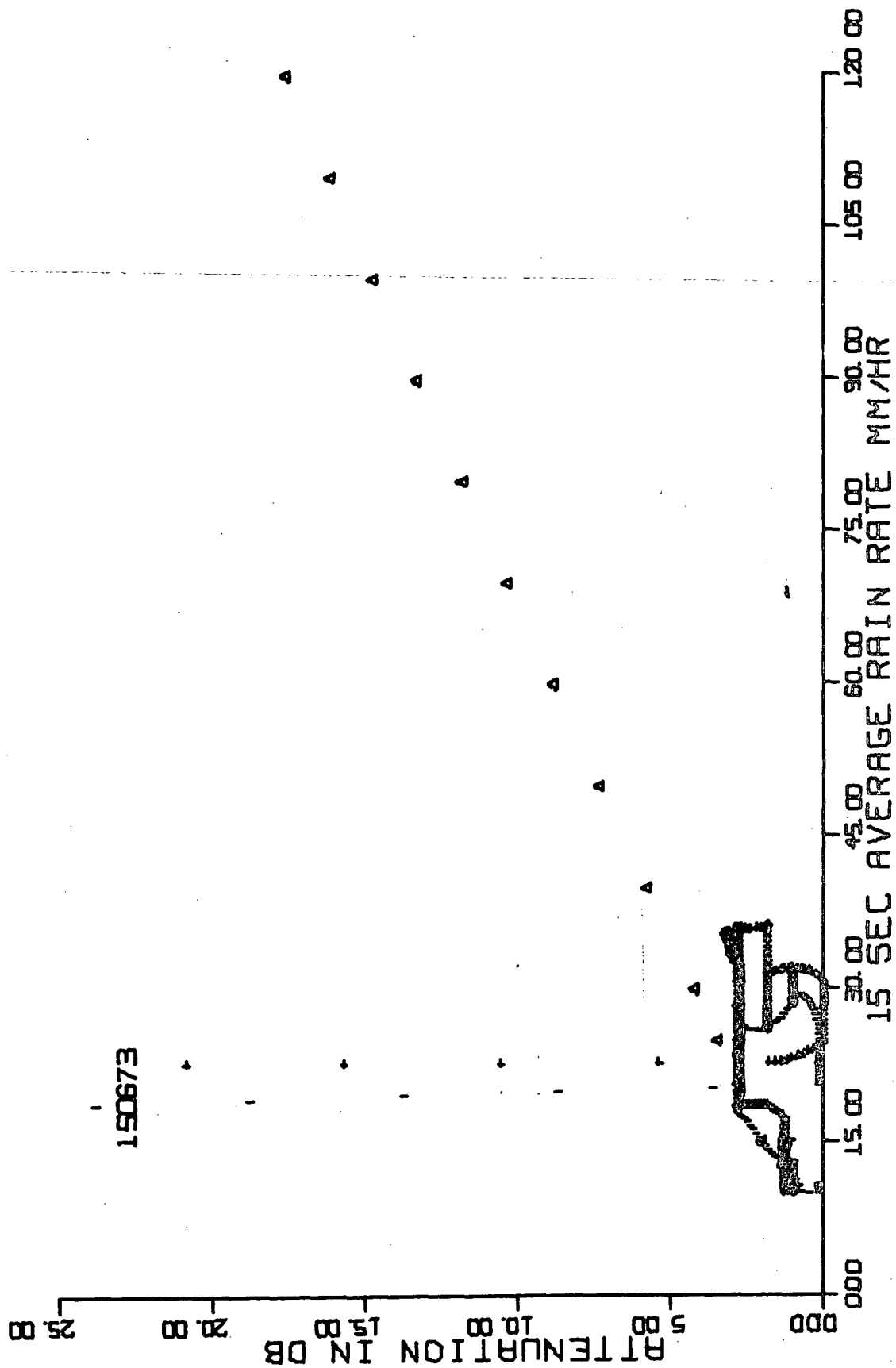


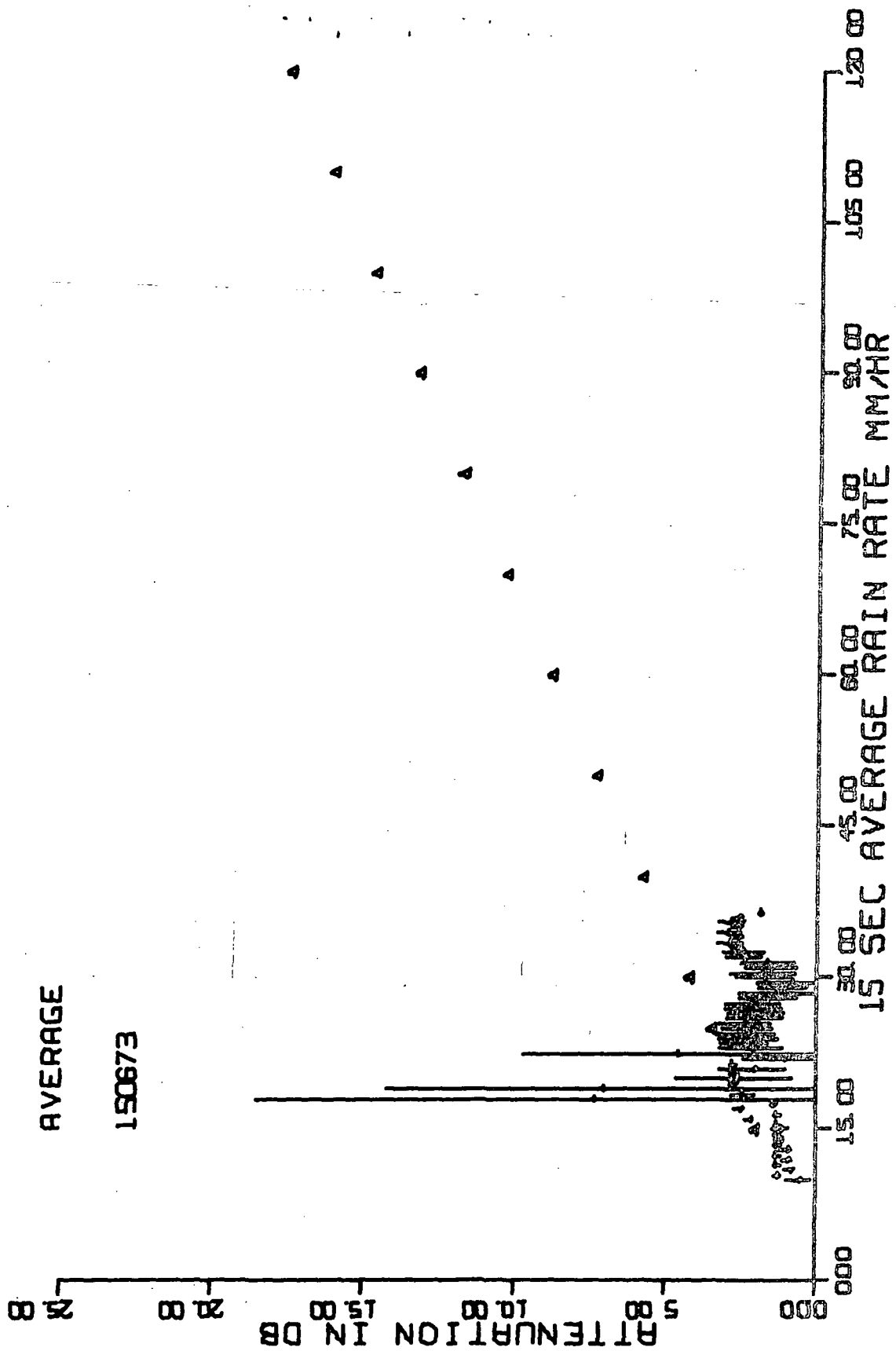


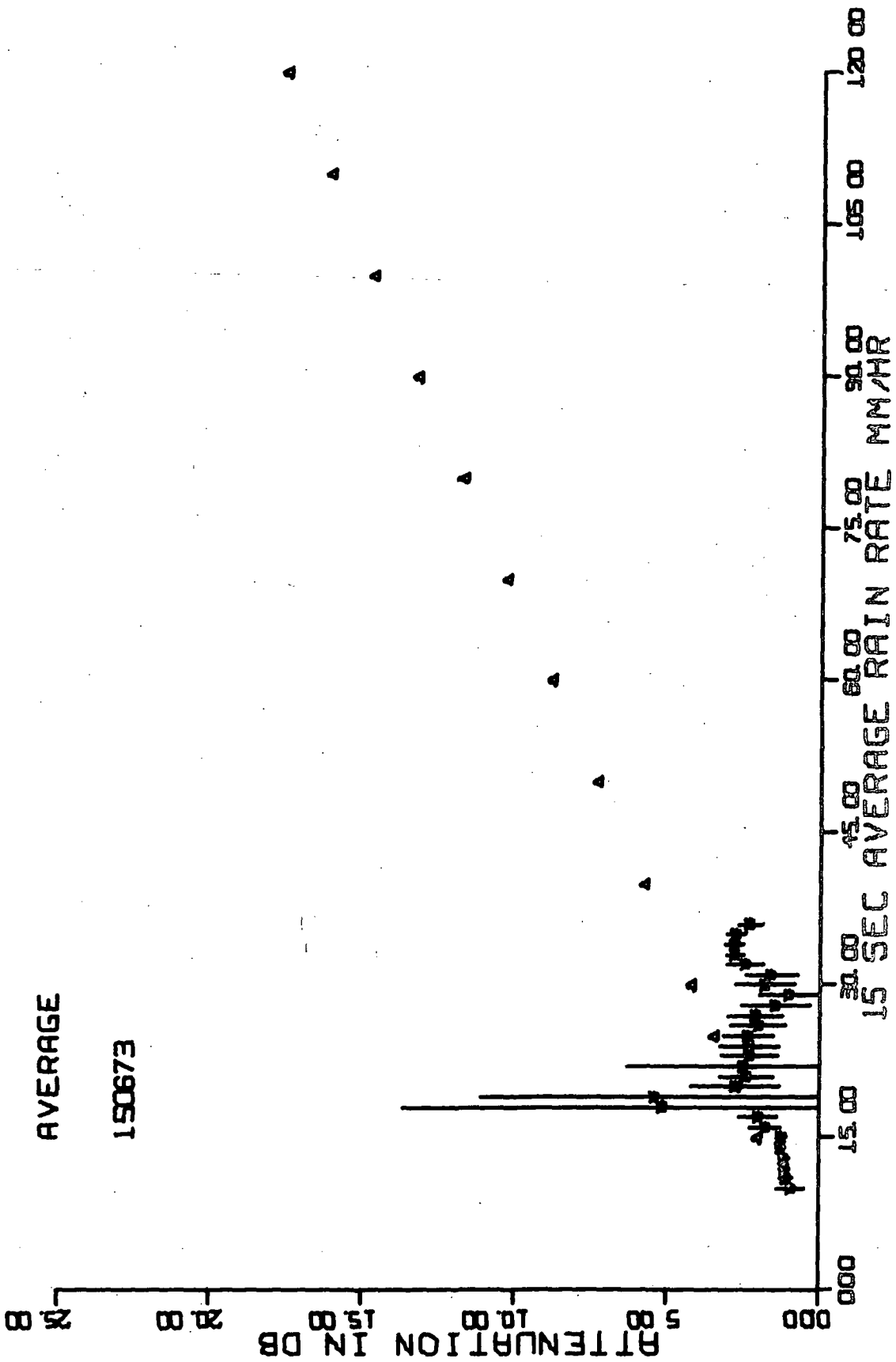


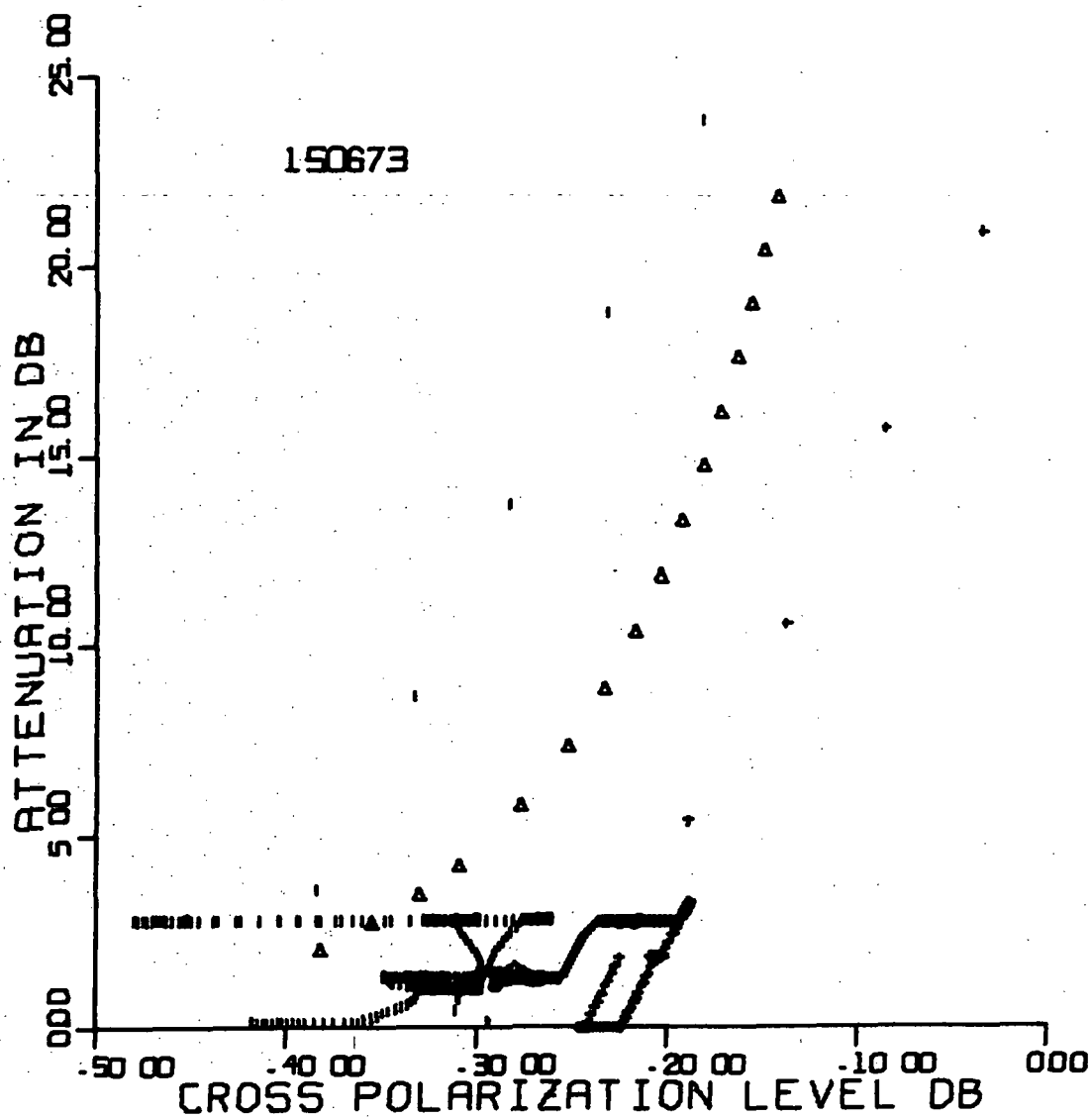


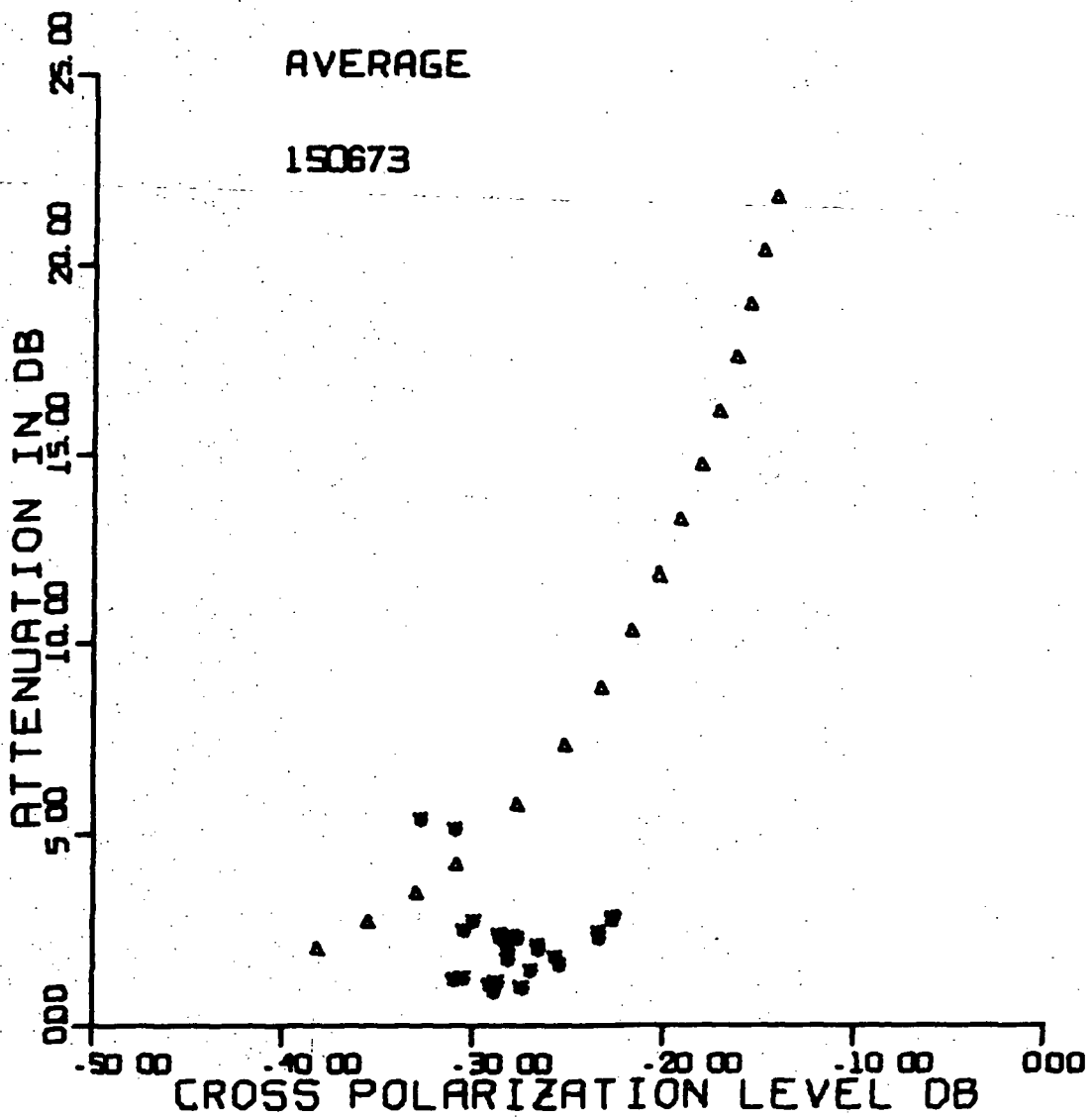


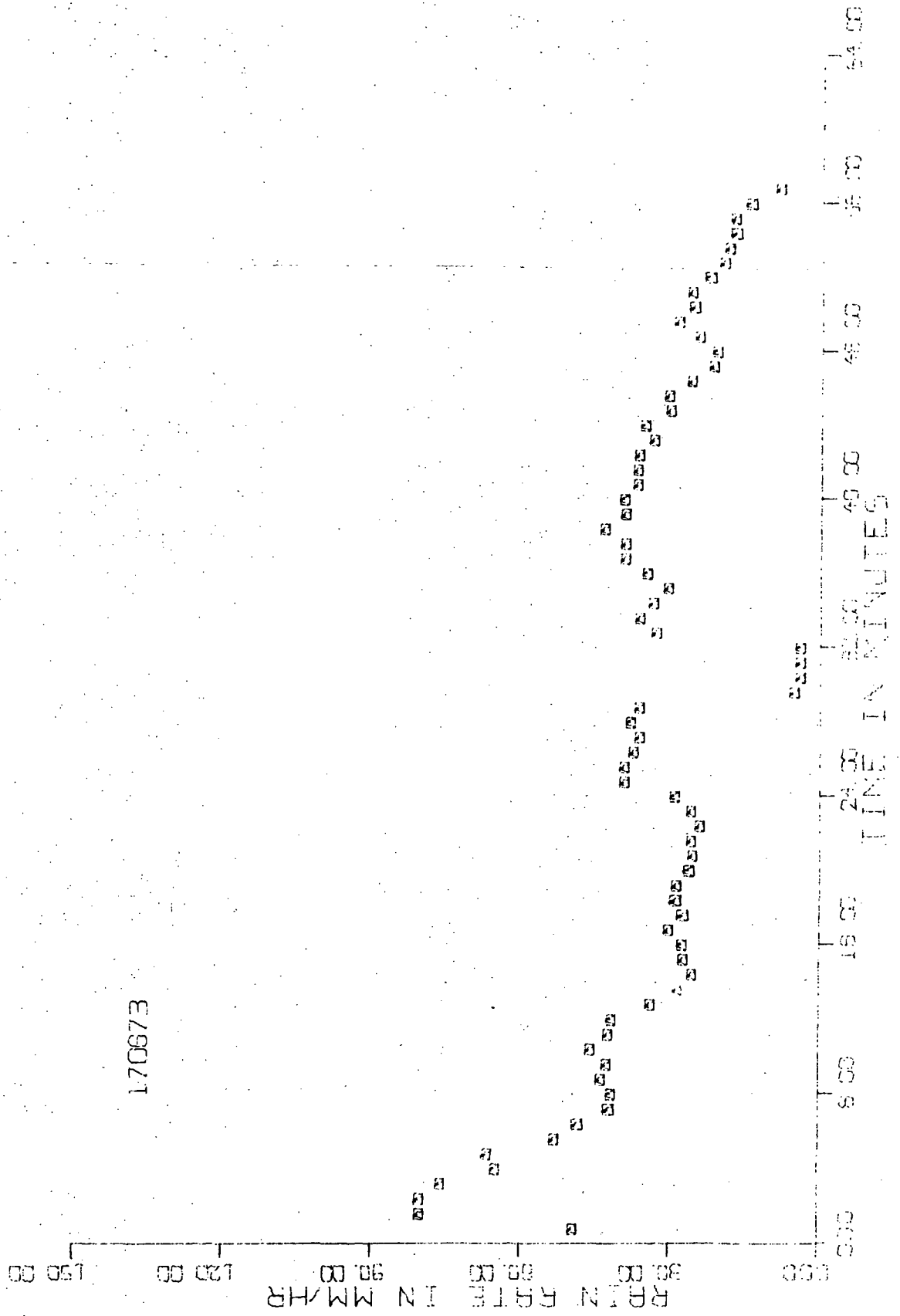


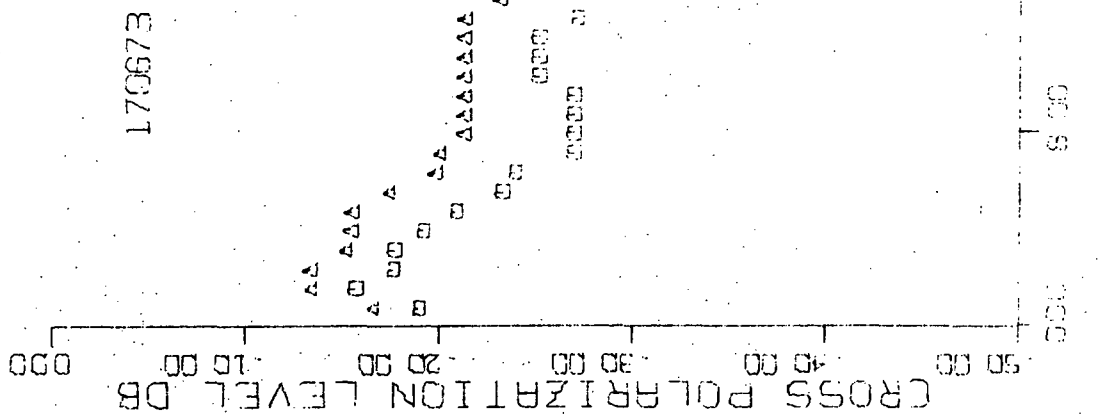


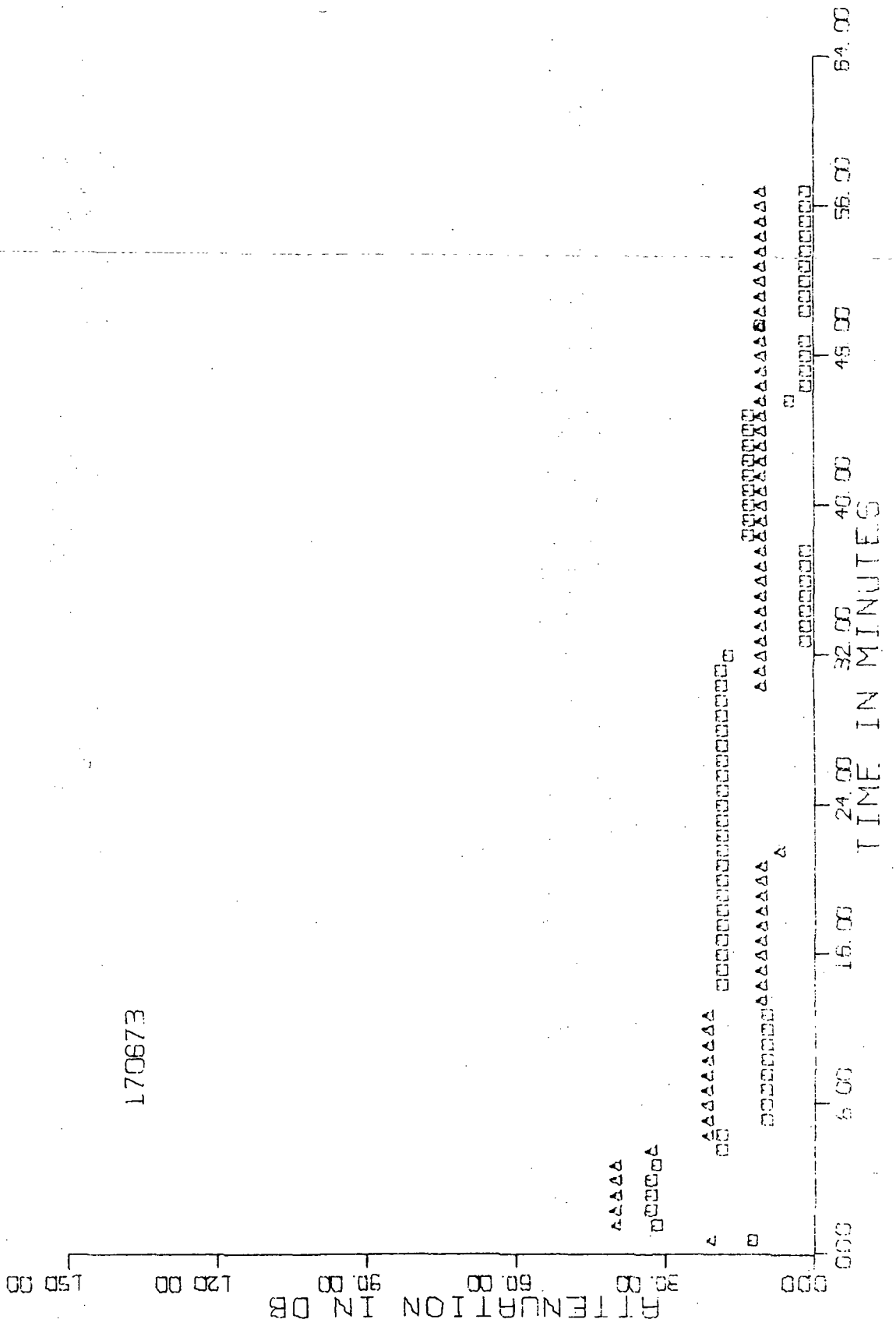


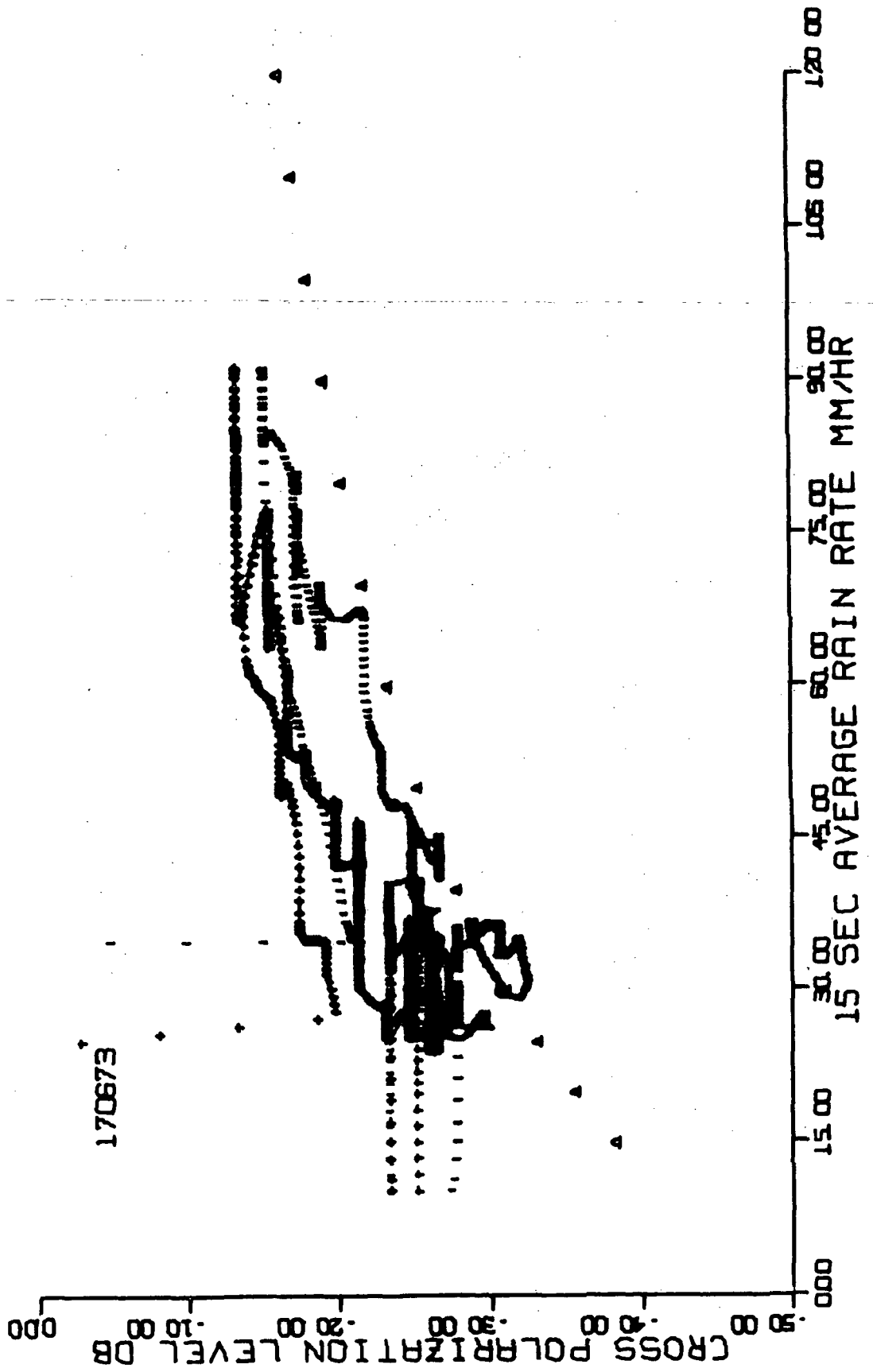


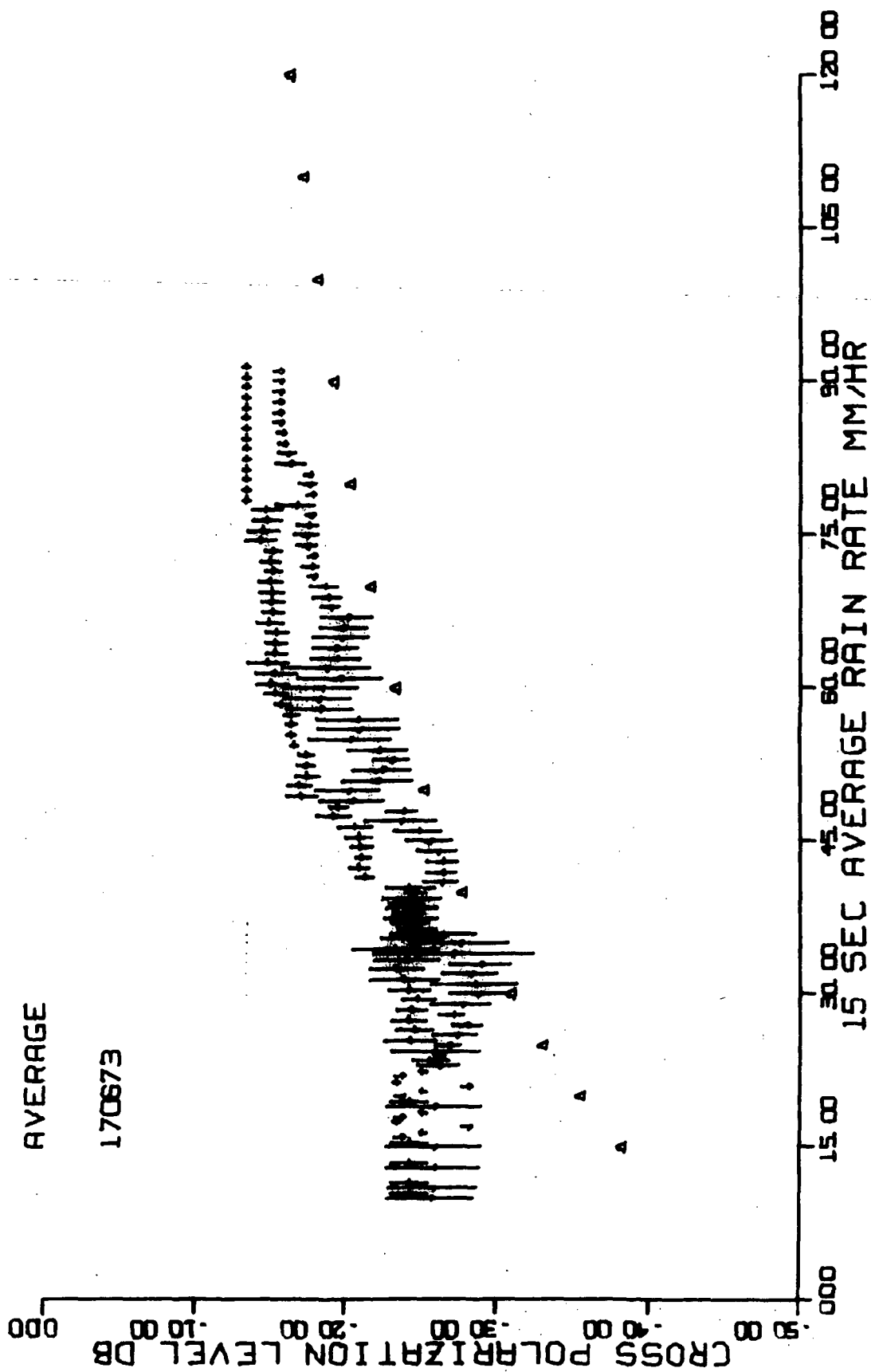


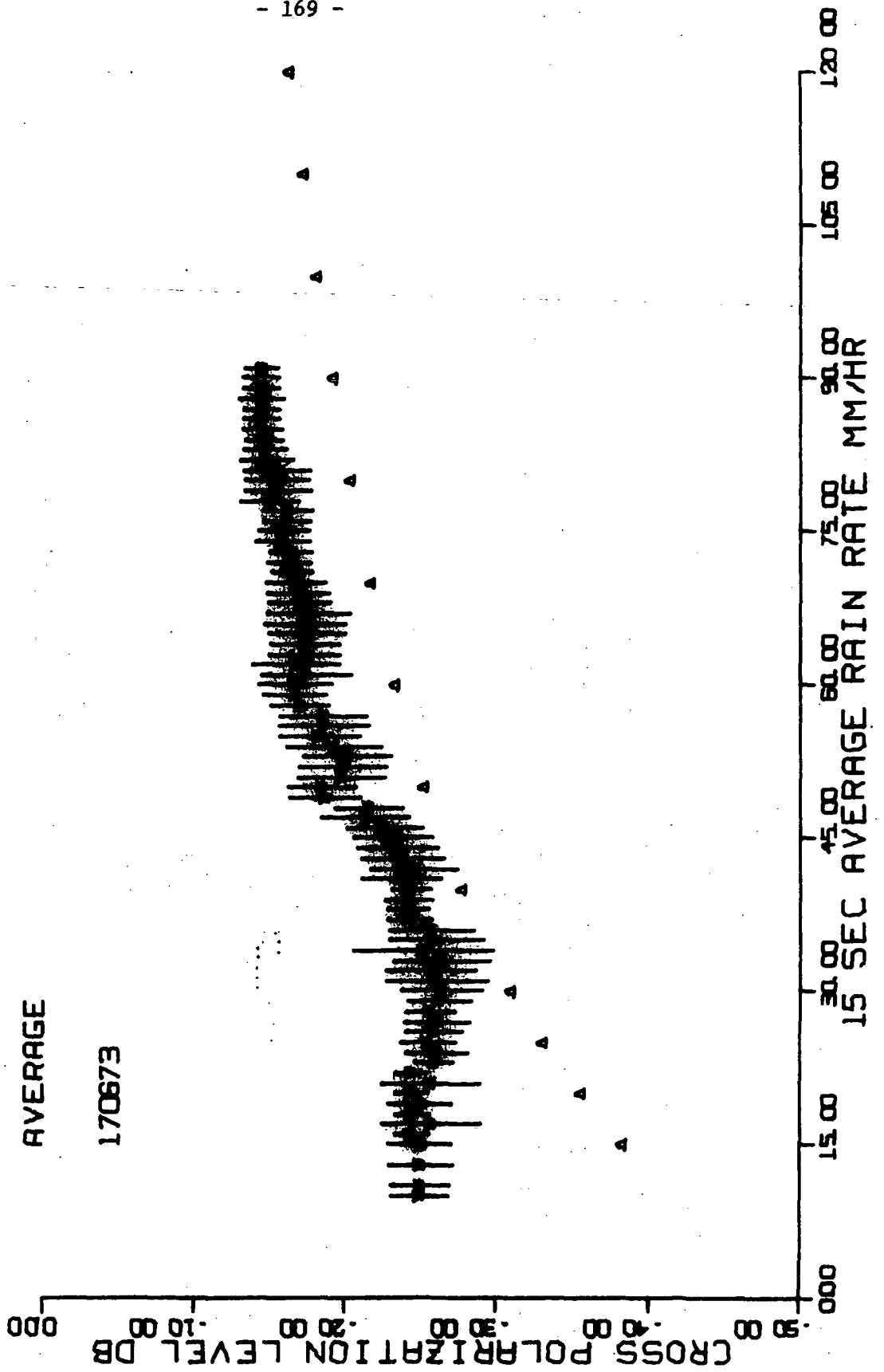


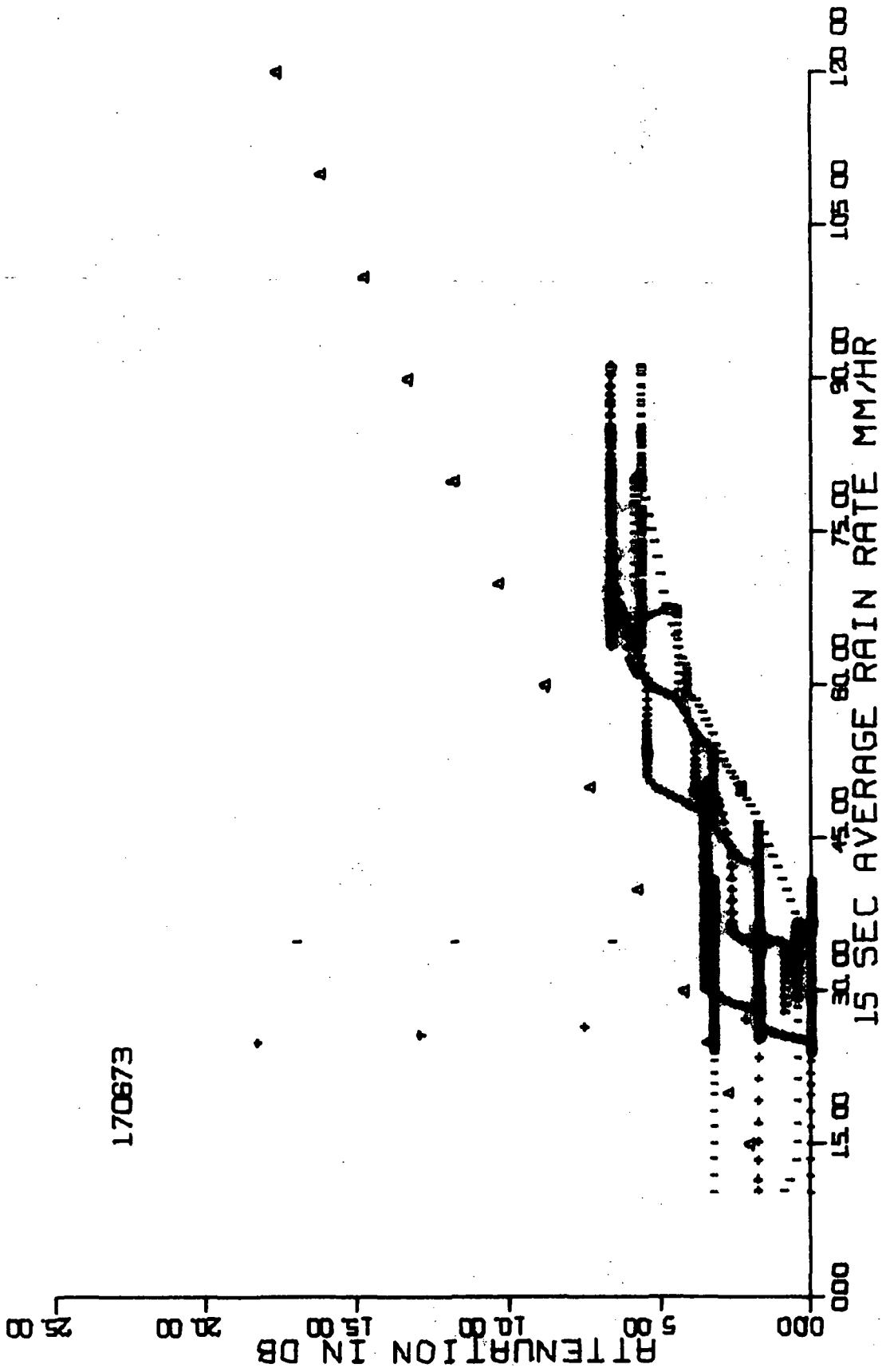


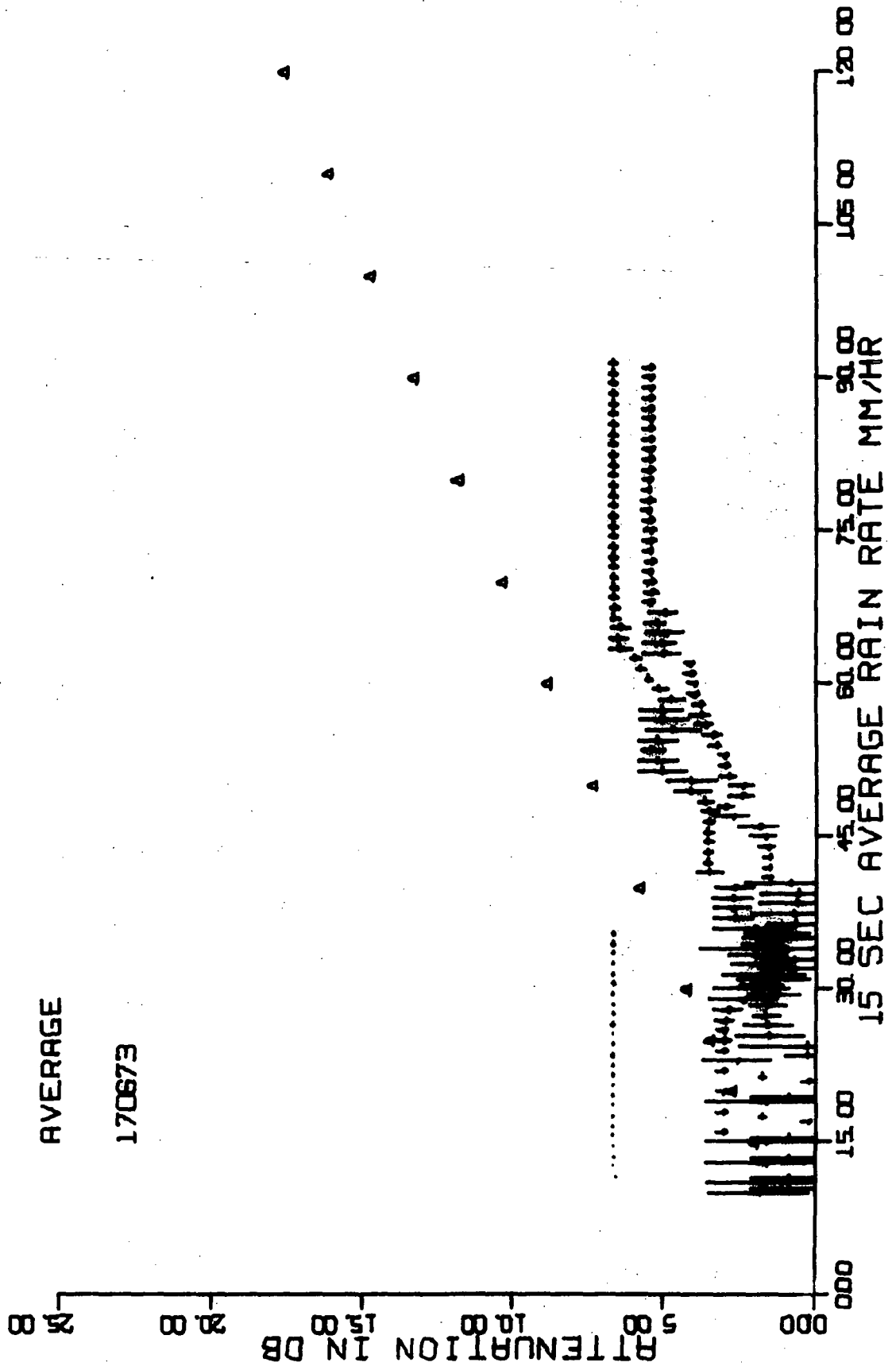


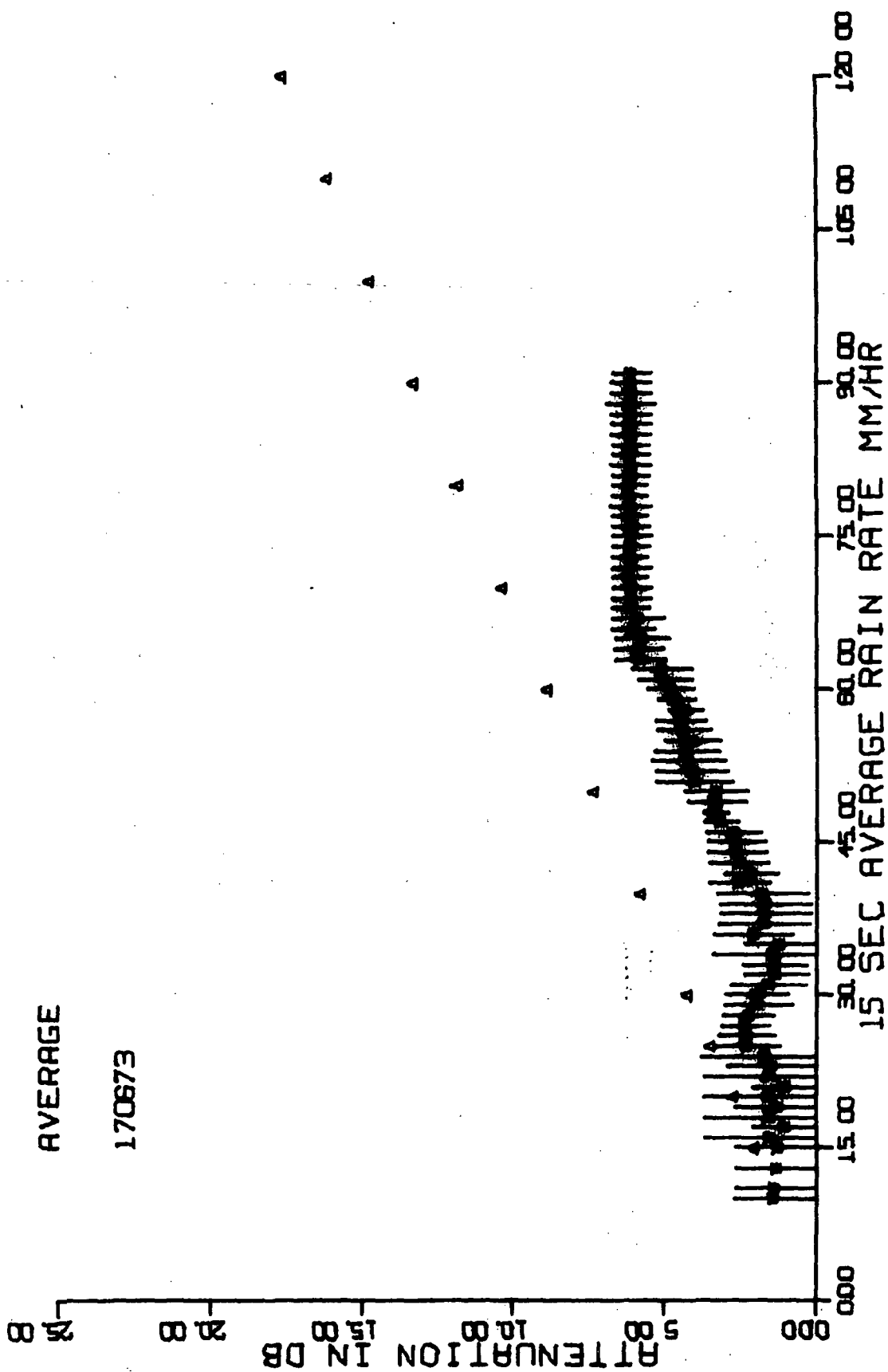


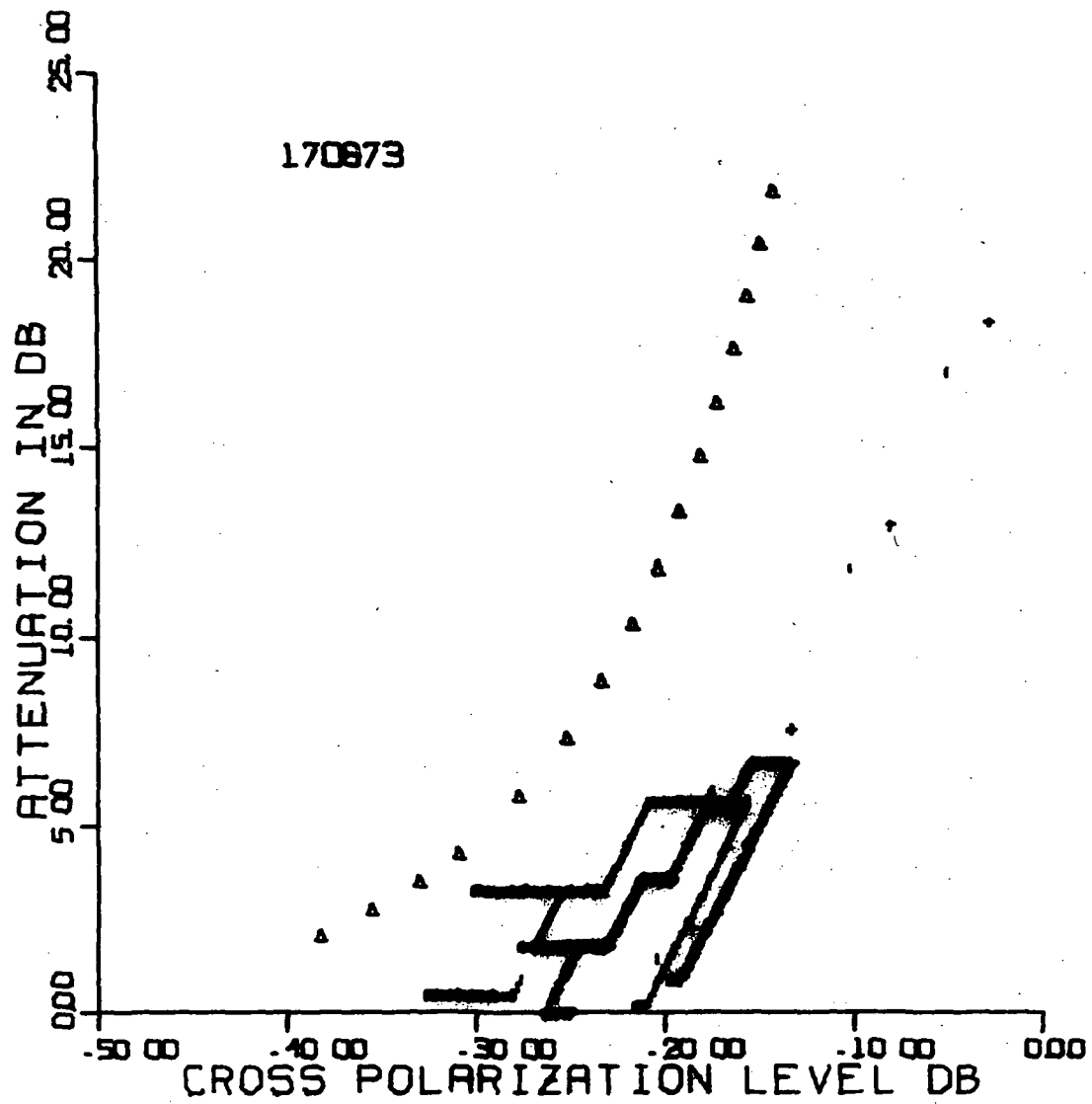


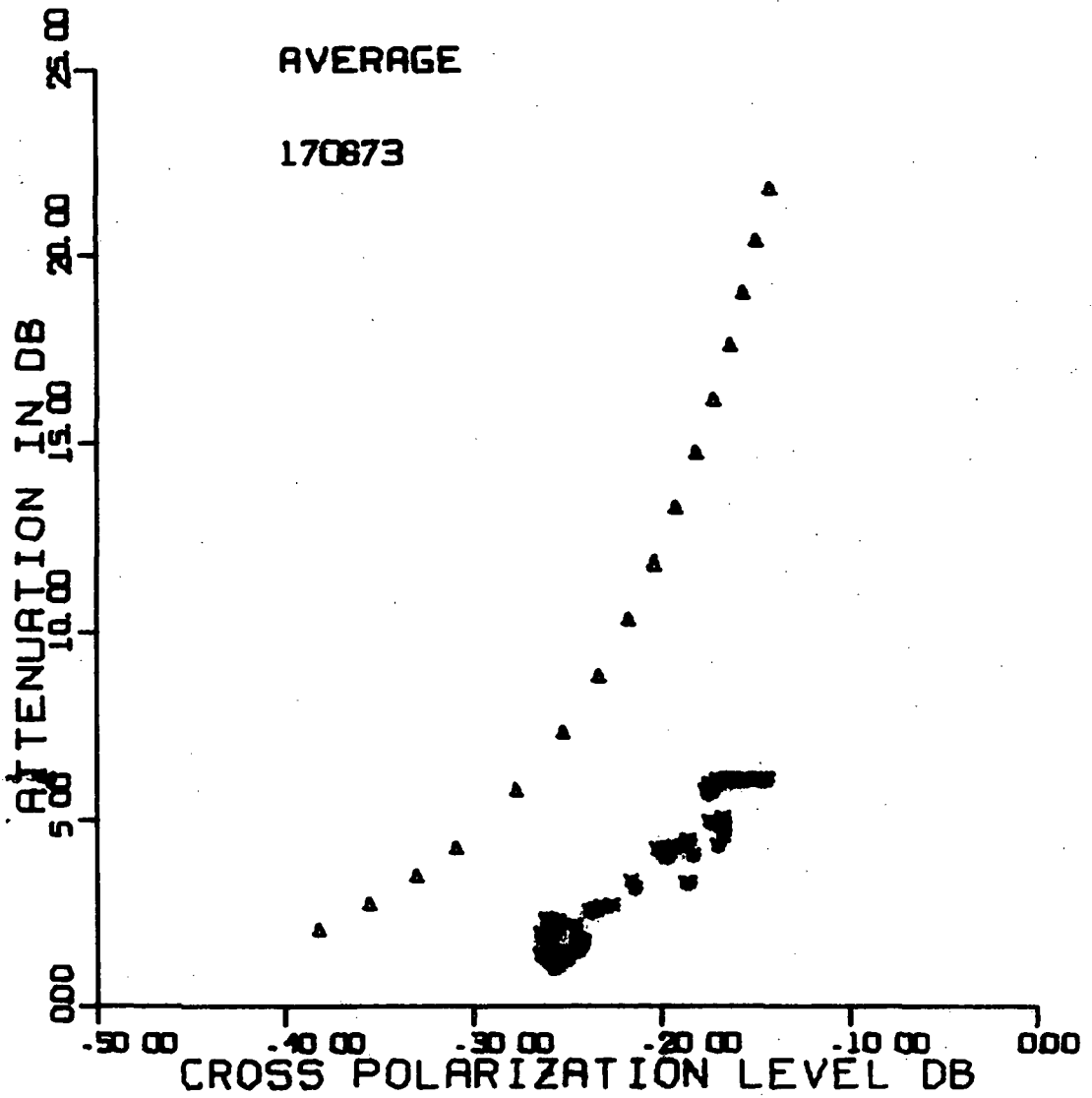


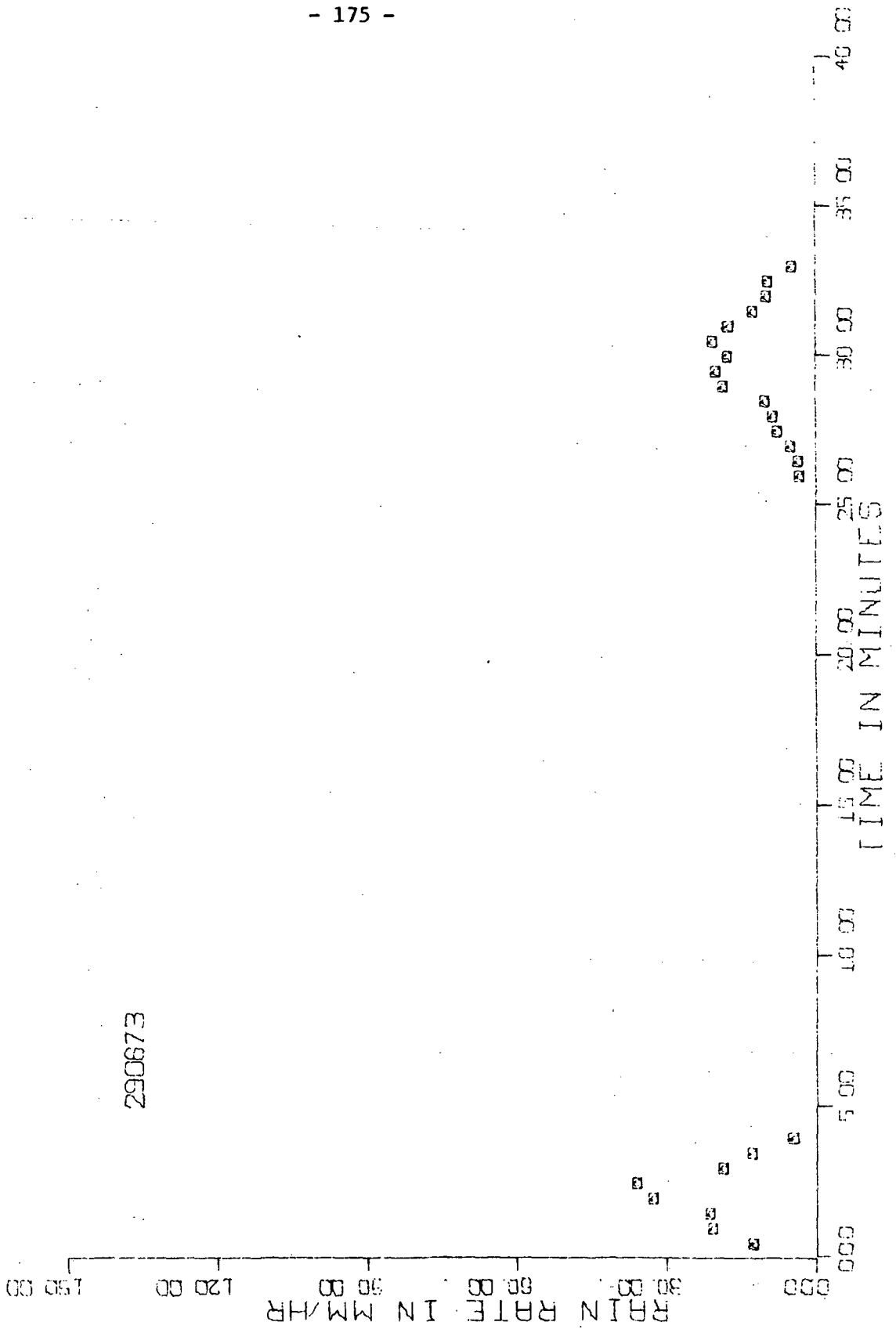


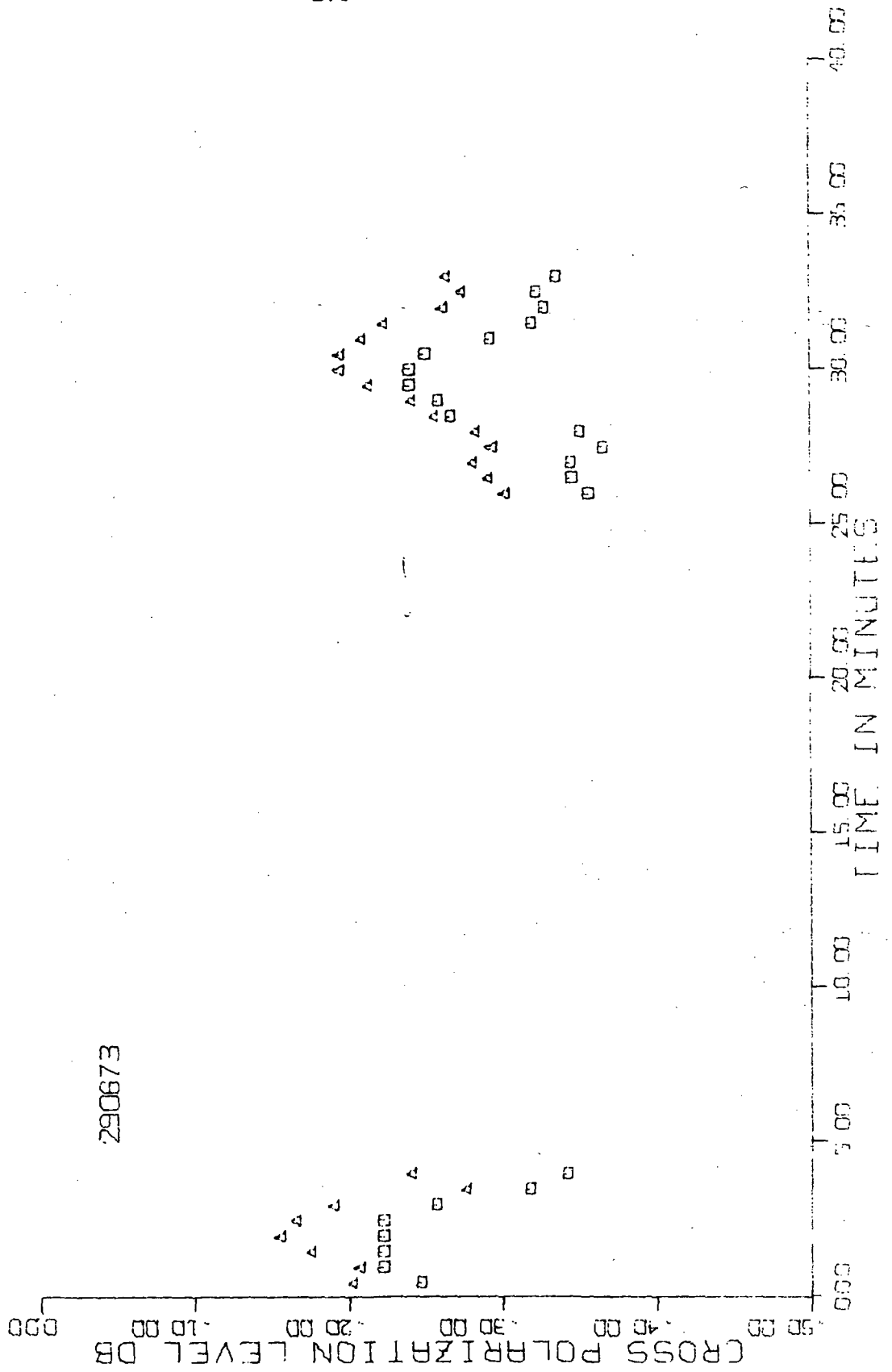












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